



ESL-TR-83-33

FUEL-RESISTANT COATING AND BINDERS FOR POROUS FRICTION SURFACE PAVEMENTS : TESTS AND ANALYSES

J.S. SHOENBERGER

GEOTECHNICAL LABORATORY

U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
P.O. BOX 631, VICKSBURG MS 39180

FEBRUARY 1984

FINAL REPORT

MAY 1980 - NOVEMBER 1983

DTIC
ELECTE
APR 6 1984
S B

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED



ENGINEERING & SERVICES LABORATORY
AIR FORCE ENGINEERING & SERVICES CENTER
TYNDALL AIR FORCE BASE, FLORIDA 32403

84 04 03 160

AD A139865

DTIC FILE COPY

NOTICE

PLEASE DO NOT REQUEST COPIES OF THIS REPORT FROM
HQ AFESC/RD (ENGINEERING AND SERVICES LABORATORY).
ADDITIONAL COPIES MAY BE PURCHASED FROM:

NATIONAL TECHNICAL INFORMATION SERVICE
5285 PORT ROYAL ROAD
SPRINGFIELD, VIRGINIA 22161

FEDERAL GOVERNMENT AGENCIES AND THEIR CONTRACTORS
REGISTERED WITH DEFENSE TECHNICAL INFORMATION CENTER
SHOULD DIRECT REQUESTS FOR COPIES OF THIS REPORT TO:

DEFENSE TECHNICAL INFORMATION CENTER
CAMERON STATION
ALEXANDRIA, VIRGINIA 22314

IMPLEMENTATION PLAN
FUEL-RESISTANT COATINGS AND BINDERS FOR POROUS FRICTION SURFACE
PAVEMENTS: TEST AND ANALYSIS
JON 20544P27

BACKGROUND


This work developed an Air Force specification of test procedures and requirements for selection of binders to construct a fuel-resistant porous friction surface (PFS). An Air Force specification of test procedures and requirements for selection of sealers to render existing PFS fuel-resistant was also developed. The procedures are very similiar, and since they are new, are verified by limited data. Additional data is being gathered in field trials at this writing to further validate their reliability and ability to render PFS fuel resistant without compromising other characteristics of the pavement. The tentative nature of these specifications and the test requirements will be adjusted as additional experience is gained.

USER

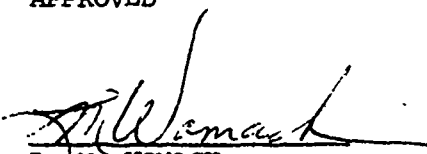
This report documents research to evaluate the ability of several products to render PFS pavements resistant to damage from jet fuel and hydraulic fluid spillage. Base personnel can use the report as a guide to select PFS materials for use in areas subject to fuel spillage. Air Force researchers will use the test procedures to evaluate test sections for fuel resistance.

ACTION

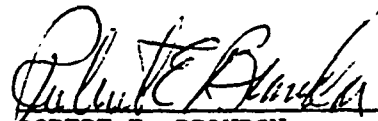
Technical reports documenting this research will be mailed to all base pavement engineers. Field validation of test procedures and requirements will be conducted Summer and Fall 1984.


JAMES G. MURFEE
Project Officer

APPROVED


L. M. WOMACK
Acting Chief, Engrg
Research Division

APPROVED


ROBERT E. BRANDON
Dep Dir, Engrg & Services
Laboratory

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ESL-TR-83-33	2. GOVT ACCESSION NO. AA-A131865	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Fuel-Resistant Coatings and Binders for Porous Friction Surface Pavements: Tests and Analyses		5. TYPE OF REPORT & PERIOD COVERED Final Report for Period, May 1980 - November 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James S. Shoenberger		8. CONTRACT OR GRANT NUMBER(s) MIPR 80-31
9. PERFORMING ORGANIZATION NAME AND ADDRESS Geotechnical Laboratory U.S. Army Engineer Waterways Experiment Station P.O. Box 631, Vicksburg MS 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PE: 64708 JON: 20544P27
11. CONTROLLING OFFICE NAME AND ADDRESS Engineering and Services Laboratory Air Force Engineering and Services Center Tyndall Air Force Base, Florida 32403		12. REPORT DATE February 1984
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 58
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution is unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Availability of Report is specified on reverse of front cover		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Pavement Design Mix Design Porous Friction Surfaces Fuel Damaged Pavements Road Tars Material Testing		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report documents research to evaluate the ability of several products to render porous friction surfaces (PFS) resistant to damage from jet fuel and hydraulic fluid spillage. Test procedures and requirements used to select fuel-resistant binders and coatings for field trials are presented in detail. One field trial using one of the products found successful in the lab, Koppers RT14, was conducted with promising results.		

PREFACE

This project was conducted between July 1980 and March 1983 by the Pavement Systems Division (PSD) of the Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under MIPR 80-31 for the U. S. Air Force Engineering and Services Center, Engineering and Services Laboratory (AFESC/RD), Tyndall Air Force Base, Florida.

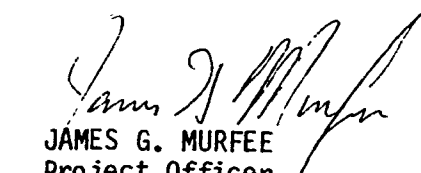
This report discusses laboratory and field testing of materials to be used as coatings and binders for Porous Friction Surface (PFS) pavements to make them resistant to jet fuel and hydraulic fluid damage. It does not constitute an endorsement of these products by the Air Force, nor can it be used for advertising the product.

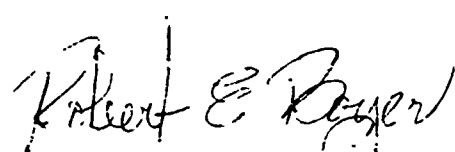
The project was performed under the general supervision of Dr. Don C. Banks, Acting Chief of GL, and Dr. William F. Marcuson III, Chief, GL. It was under the direct supervision of Mr. Jim W. Hall, Jr., Acting Chief of PSD, Dr. T. D. White, Chief, PSD, and Dr. Elton R. Brown, Chief of the Material Research Center, PSD. This report was prepared by Mr. James E. Shoenberger. Commanders and Directors of WES during the period of the project and the preparation of this report were Col Nelson P. Conover, CE, and Col Tilford C. Creel, CE. Technical Director was Mr. Fred R. Brown.

The Air Force Engineering and Services Center Project Officers were Lt R. A. McDonald and Mr. J. G. Murfee.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.


JAMES G. MURFEE
Project Officer


ROBERT E. BOYER, Col, USAF
Director, Engineering and
Services Laboratory


L. M. WOMACK
Acting Chief, Engineering
Research Division



Accession For	
NTIS GRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

1
(The reverse of this page is blank.)

TABLE OF CONTENTS

Section	Title	Page
I	INTRODUCTION.....	1
	A. BACKGROUND.....	1
	B. OBJECTIVE.....	1
	C. SCOPE.....	1
II	PRODUCT SURVEY.....	3
III	LABORATORY STUDY.....	4
	A. MATERIALS FOR TESTING.....	4
	1. Products Tested.....	4
	2. Aggregate.....	4
	3. Gradation.....	4
	4. Test Fluids.....	5
	B. DEVELOPMENT OF TEST METHODS.....	5
	1. Permeability Test Device.....	5
	2. Hydraulic Fluid Test.....	5
	3. Fuel-Drip Test.....	8
	4. Abrasion Test.....	9
	C. POROUS FRICTION SURFACE COATINGS.....	9
	1. Material Preparation.....	9
	2. Specimen Preparation.....	13
	3. Compaction Methods.....	13
	4. Coating Procedure.....	13
	5. Curing.....	14
	6. Initial Screening.....	14
	7. Results of Initial Screening.....	14
	8. Test Results.....	15
	D. POROUS FRICTION SURFACE BINDERS.....	20
	1. Material Preparation.....	20
	2. Specimen Preparation.....	20
	3. Curing.....	21
	4. Binder Content.....	21
	5. Tests.....	21
	6. Results.....	21
IV	FIELD TEST STUDY.....	26
	A. MATERIALS.....	26
	1. Aggregate.....	26
	2. Binders.....	26

TABLE OF CONTENTS
(CONCLUDED)

Section	Title	Page
B.	CONSTRUCTION.....	28
C.	TESTING.....	28
	1. Fuel Spills.....	28
	2. Traffic.....	32
D.	RESULTS.....	32
	1. AC-20 Asphalt.....	32
	2. RT-14 Tar.....	35
V	CONCLUSIONS AND RECOMMENDATIONS.....	37
	A. CONCLUSIONS.....	37
	B. RECOMMENDATIONS.....	38
VI	REFERENCES.....	39
APPENDIX		
A	COATINGS FOR FUEL-RESISTANT POROUS FRICTION SURFACE (PFS) PAVEMENTS: TENTATIVE MATERIAL SPECIFICATIONS.....	41
B	BINDERS FOR FUEL-RESISTANT POROUS FRICTION SURFACE (PFS) PAVEMENTS: TENTATIVE MATERIAL SPECIFICATIONS.....	50
C	CONVERSION FACTORS, U. S. CUSTOMARY (NON-SI) TO METRIC (SI) UNITS OF MEASUREMENT.....	59

LIST OF FIGURES

Figure	Title	Page
1	Parts of the Permeability Test Device.....	6
2	Permeability Test Device Details.....	7
3	Permeability Test Device.....	8
4	Fuel-Drip Test Device.....	9
5	Abrasion Test Device.....	10
6	Closeup of Abrasion Test Device.....	10
7	Gyratory Compaction Machine.....	14
8	Product D, After Coating but Before Testing.....	17
9	Product D, After Testing.....	17
10	Product K, After Coating but Before Testing.....	19
11	Product K, After Testing.....	19
12	Product F, Before Testing.....	23
13	Product F, After Testing.....	23
14	Product J, Before Testing.....	25
15	Product J, After Testing.....	25
16	Porous Friction Surface (PFS) Test Section, Before Fuel Spills and Traffic.....	27
17	Surface Texture of RT-14 Tar PFS.....	27
18	Placing of Tack Coat for PFS Test Sections.....	29
19	Construction of PFS Test Sections.....	29
20	Layout of PFS Test Sections.....	30
21	Spilling of Hydraulic Fluid on PFS Test Sections.....	31
22	Flushing RE-14 Tar PFS with Low-Pressure Water Hose...	32
23	Drainage from AC-20 Asphalt PFS Test Section, Approximately 30 Minutes After Testing.....	33
24	F-4 Load Cart.....	33

LIST OF FIGURES
(CONCLUDED)

Figure	Title	Page
25	Rutting in Section 3 of AC-20 Asphalt PFS Test Section.....	34
26	Fuel Drainage Through PFS.....	34
27	Water-Fuel Mixture Remaining on AC-20 Asphalt PFS After Flushing JP-4 Spill with Water.....	35
28	Raveling and Rutting of AC-20 Asphalt PFS.....	36
29	RT-14 Tar PFS (Left) Receiving F-4 Traffic.....	36

LIST OF TABLES

Table	Title	Page
1	SUMMARY OF MATERIAL TYPES AND PRODUCTS TESTED.....	2
2	LABORATORY POROUS FRICTION SURFACE (PFS) AGGREGATE GRADATION.....	4
3	EVALUATION OF MATERIALS AS FUEL-RESISTANT PFS COATINGS.....	11
4	EVALUATION OF MATERIALS AS FUEL-RESISTANT PFS BINDERS.....	16
5	FIELD TEST PFS AGGREGATE GRADATION.....	26
6	FUEL SPILLAGE QUANTITIES FOR PFS TEST SECTIONS.....	31
A-1	AGGREGATE GRADATION FOR POROUS FRICTION SURFACE COATINGS, LABORATORY SPECIMENS.....	43
B-1	AGGREGATE GRADATION FOR POROUS FRICTION SURFACE BINDERS, LABORATORY SPECIMENS.....	52

SECTION I

INTRODUCTION

A. BACKGROUND

Porous Friction Surface (PFS) pavements have been widely used by the Air Force to prevent hydroplaning since their introduction in the mid-1960s. A PFS is an open-graded, free-draining, bituminous mixture used to prevent hydroplaning, water splashing, and loss of wet traction. It is mixed in a central plant and usually applied at a thickness of 3/4 to 1 inch* using conventional paving methods.

Problems occur, however, when fuel is spilled on a PFS pavement because it permeates the voids and dissolves the bituminous material causing further damage to any underlying bituminous pavement. Furthermore, these spills of jet fuel or hydraulic fluid can cause foreign object damage (FOD) as they destroy the pavement surface. The standard practice has been to wash with water the areas where fuel has been spilled to minimize damage. Often the runway must be patched when the damage is severe enough, necessitating the closing of part or all of the runway. Consequently, there is a need to develop fuel-resistant coatings for application to existing PFS pavements and fuel-resistant binders for use in PFS pavement construction where fuel spills are anticipated. Development of such fuel-resistant materials will result in a significant improvement in Air Force operational capabilities relative to PFS runways.

B. OBJECTIVE

The objective is to perform laboratory and field evaluations of materials for making PFS pavements resistant to damage from jet fuel and hydraulic fluid.

C. SCOPE

An investigation was conducted for available products that would meet the fuel-resistance requirements. Material producers were contacted and encouraged to submit applicable products for laboratory testing. Table 1 lists the material types and mixtures tested. These products were tested for fuel resistance using a fuel-drip test and an abrasion test to help quantify the results. Also, material specifications for fuel-resistant PFS materials were developed (see Appendixes A and B). A test section was constructed for a field evaluation of RT-14 (road tar), one of the products selected from the laboratory testing as a satisfactory fuel-resistant binder.

* A table of factors for converting U. S. customary (NON-SI) to metric (SI) units of measurement is presented in Appendix C.

TABLE 1. SUMMARY OF MATERIAL TYPES AND PRODUCTS TESTED.

Symbol	Manufacturer	Product	Type of Material	Mixture	Price/ gallon ^a
A	Adhesive Engineering Co. San Carlos, California	AEX - 1480	Epoxy resin	1 part A to 5 parts B	\$22.65
B	Adhesive Engineering Co. San Carlos, California	Concresive epoxy asphalt (A)1152 + (B)1179	Epoxy asphalt	14.6 parts A to 85.4 parts B	---
b ^c	American Protective Coatings Corp. Cleveland, Ohio	No. 21 epoxy	Coal tar epoxy	1 part binder to 2 parts activator	18.52
b ^d	American Protective Coatings Corp. Cleveland, Ohio	No. 21 epoxy (penetrating type)	Coal tar epoxy	1 part binder to 2 parts activator	18.52
E	Dural International Corp. Deer Park, New York	No. 306 epoxy	Coal tar epoxy	1 part base to 1 part hardener	16.65
F	Emulsified Asphalt Inc. Chicago, Illinois	GRS-R	Coal tar emulsion	Water added as required	1.00
G	Emulsified Asphalt Inc. Chicago, Illinois	GRS-IL	Coal tar emulsion	Water added as required	1.00
H	Isochem Resins Co. Lincoln, Rhode Island	Sol epoxy	Epoxy resin	4 parts hardener to 10 parts resin	---
I	Koppers Co., Inc. Monroeville, Pennsylvania	Coal tar emulsion	Coal tar emulsion	Water added as required	1.00
J	Koppers Co., Inc. Monroeville, Pennsylvania	RT-14	Tar	No admixtures required	2.00
K	Midwest Industrial Products Corp. Chicago, Illinois	Z-40	Coal tar pitch emulsion	Water added as required	1.00
L	Rub-R-Road, Inc. Akron, Ohio	(A)R-5268 + (B)R-607	Rubberized sealant	1 part thinner (B) to 3 parts binder (A)	12.57
M	Sahuaro Petroleum and Asphalt Co. Phoenix, Arizona	Plastic seal	Plastic-asphalt	1 part water to 2 parts emulsion	---
N	Union Carbide Corp. Indianapolis, Indiana	EO-A70	Polyvinyl acetate	Water added as required	---
O	Uniroyal, Inc. Mishawaka, Iowa	M-6249	Rubberized adhesive	2 parts acetone to 3 parts adhesive (coating) 1 part acetone to 2 parts adhesive (binder)	13.12
P	Uniroyal, Inc. Mishawaka, Iowa	M-6136	Rubberized adhesive	2 parts acetone to 3 parts adhesive (coating) 1 part acetone to 2 parts adhesive (binder)	13.22

^a Tentative prices for Fall 1961.^c Products C and D, manufactured by the same company, are similar products; however, D is formulated with a lower viscosity.

SECTION II

PRODUCT SURVEY

Since materials for sealing and protecting pavements in areas of fuel spillage have been marketed for several years, an extensive review of all available products on the market was made. Material producers were contacted for information on any products available as fuel-resistant sealers or binders, and they were requested to submit products believed to be suitable for this application. Most products available have been designed to perform as fuel-resistant seal coats. Of the products surveyed, only Product B, which has been used on several bridge decks, has been previously utilized in a porous surface overlay. Several companies contacted which formerly produced fuel-resistant binders (epoxy asphalts, epoxy resins, coal tar epoxy) had stopped marketing these materials due to long-term performance problems and/or the lack of a market for their products. There had been little experience with the performance of many of the materials when used as coating or binding materials for pavements.

SECTION III

LABORATORY STUDY

The laboratory study was divided into two phases. In Phase I the materials were tested as coatings for PFS pavements, and in Phase II they were tested as binders for new PFS construction.

A procedure to test the products when exposed to dripping fuel and an abrasion test to quantify mixture damage were developed. Since literature research revealed no standard tests which would directly apply to these requirements, methods suitable for determining the fuel-resistance effectiveness of various types of products to be tested had to be developed. A fuel-drip test rather than an immersion test was adopted because it more nearly simulated actual field conditions. The permeability of the specimens was determined, using a falling-head permeability test device previously developed at WES (Reference 1). A method was developed to drip a predetermined amount of fuel on a specimen in a specified time frame. A test developed for slurry seal design (Reference 2) was adapted for use in the abrasion test.

A. MATERIALS FOR TESTING

1. Products Tested

Table 1 contains a listing and brief description of all the types of products tested.

2. Aggregate

The aggregate used in preparing the laboratory specimens was a crushed Alabama limestone with a specific gravity of 2.72 and water absorption of 0.4 percent.

3. Gradation

The aggregate gradation used for the PFS mix is shown in Table 2.

TABLE 2. LABORATORY POROUS FRICTION SURFACE (PFS)
AGGREGATE GRADATION

Sieve Designation (Square Openings)	Percent Passing by Weight of Total Aggregates	
	Actual	Specification Required ^a
3/4 inch	100	100
1/2 inch	100	70-100
3/8 inch	92	45- 75

(Continued)

TABLE 2. LABORATORY POROUS FRICTION SURFACE (PFS)
AGGREGATE GRADATION (CONCLUDED)

Sieve Designation (Square Openings)	Percent Passing by Weight of Total Aggregates	
	Actual	Specification Required ^a
No. 4	37	25- 40
No. 8	17	10- 20
No. 30	9.1	3- 7
No. 200	3.9	0- 5

^aCEGS-02562, Porous Friction Course for airfields and roads.

4. Test Fluids

JP-4 is the standard aviation fuel used by the U. S. Air Force. To eliminate the possibility of slight variations in the performance of JP-4 obtained from different sources, an ASTM reference fuel (Reference 3) (Reference Fuel B) was used for this study. Reference Fuel B is composed of 70 percent isooctane and 30 percent toluene by volume. A previous study (Reference 4) demonstrated that this fuel mixture would perform similar to JP-4 when compared for detrimental effects on various materials.

Also used in the study was a standard general-purpose hydraulic fluid equivalent to that used by the Air Force. Hydraulic fluid has been shown to be detrimental to asphalt cement pavements (Reference 5). The relatively long-term effects of hydraulic fluid on a PFS must be considered because, unlike jet fuel which will evaporate rather quickly, hydraulic fluid will remain in the pavement much longer.

B. DEVELOPMENT OF TEST METHODS

1. Permeability Test Device

A suitable permeability test device has been developed at WES to determine the permeability of PFS mixtures (see Figures 1, 2, and 3). This device, which is applicable to both field and laboratory conditions, can be used on pavement cores with a minimum diameter of 6 inches as shown in Figure 3 or on the in-place pavement.

2. Hydraulic Fluid Test

The test developed consisted of placing the specimens, PFS side down, in approximately 1/2 inch of hydraulic fluid and, periodically, visually examining the effects. Tests were conducted with products which exhibited both high and low fuel resistance, including a plain asphalt (control specimen) PFS.

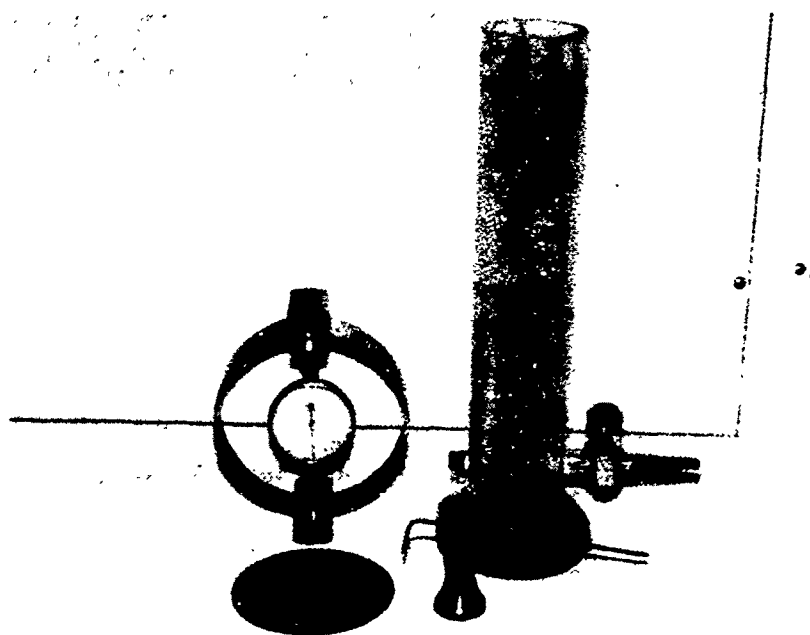


Figure 1. Parts of the Permeability Test Device.

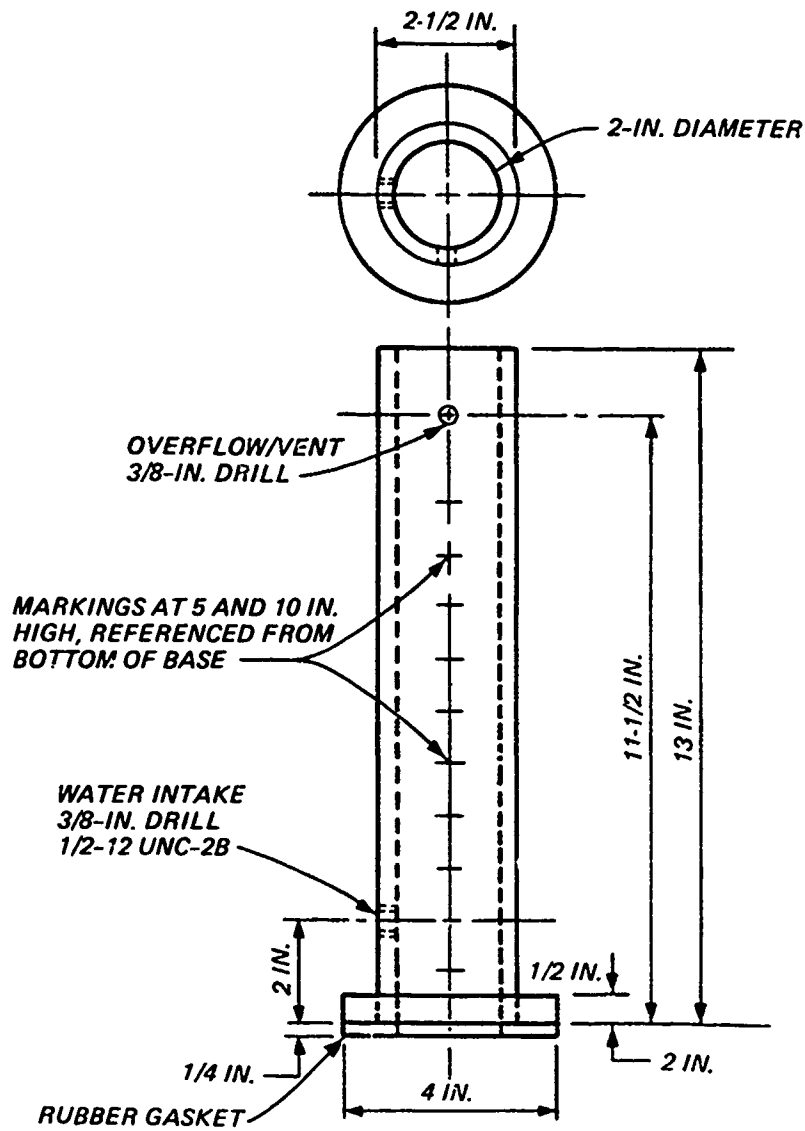


Figure 2. Permeability Test Device Details.

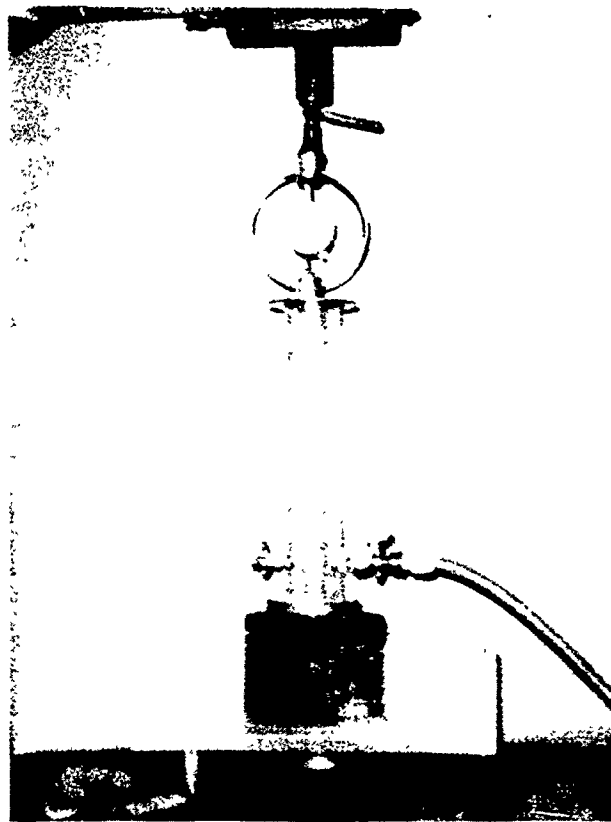


Figure 3. Permeability Test Device.

The specimens were originally inspected every 1/2 hour, but inspection intervals were later changed to 1, 2, 4, 6, and 24 hours after immersion. The longer soaking periods were applicable because hydraulic fluid will evaporate very slowly, and, despite flushing a spill area with water, a coating of the fluid will remain on the PFS for an extended period.

3. Fuel-Drip Test

Since no applicable standard fuel-drip test was available, one was developed during the course of the laboratory testing. Simulation of possible fuel spillage situations was accomplished by developing the amount and proper time frame for the spillage. Enough fuel was used to keep the surface of the specimens saturated during the test. From the initial fuel tests it was determined that a total of 1000 milliliters of fuel dripped for 10 minutes would fulfill this requirement. Initially, the fuel was dripped by gravity feed, but later the container was pressurized at 5 pounds per square inch (psi), to obtain a constant flow. The material was allowed to drip onto the specimens from a height of approximately 2 inches. The specimens were rotated 90 degrees every 2 1/2 minutes to assure uniform coverage and then placed on a wire screen over a pan during the fuel dripping to allow for drainage of the excess fuel (see Figure 4). Each 10-minute cycle of dripping fuel was considered equal to one fuel spill in the field.



Figure 4. Fuel-Drip Test Device.

4. Abrasion Test

An abrasion test to simulate effects of traffic was developed using an adaptation of the Wet Track Abrasion Test (WTAT) device (Reference 2) as shown in Figure 5. The 6-inch-diameter test specimens were large enough for use on the adapted test machine and were still small enough for convenient preparation. The changes made to the test device were minimal, with a specimen holder being the only new piece of equipment necessary. The abrasion hose used was shortened from 5 to 1 1/2 inches because of the reduced size of the test specimen (See Figure 6). The original procedure developed consisted of abrading each test specimen as soon as its weight stabilized after the fuel-drip test (all the residual fuel evaporated). During the initial product screening it was observed that most of the PFS caps softened during the fuel-drip test but then hardened again after the fuel had evaporated. The time required for this hardening to take place varied from about one hour to several hours depending on the coating tested. It was decided to test the specimens by abrasion within 30 ± 1 minutes after completing the fuel-drip test. The specimen hose used was completely immersed in water as in the normal WTAT to help prevent friction heat buildup.

C. POROUS FRICTION SURFACE COATINGS

1. Material Preparation

The materials were prepared according to the manufacturers' specifications (see Table 3). Some of the materials were diluted at various rates while other materials required no dilution. Each product was allowed to cure for a minimum of 24 hours or until the surface was tack-free, whichever was greater.

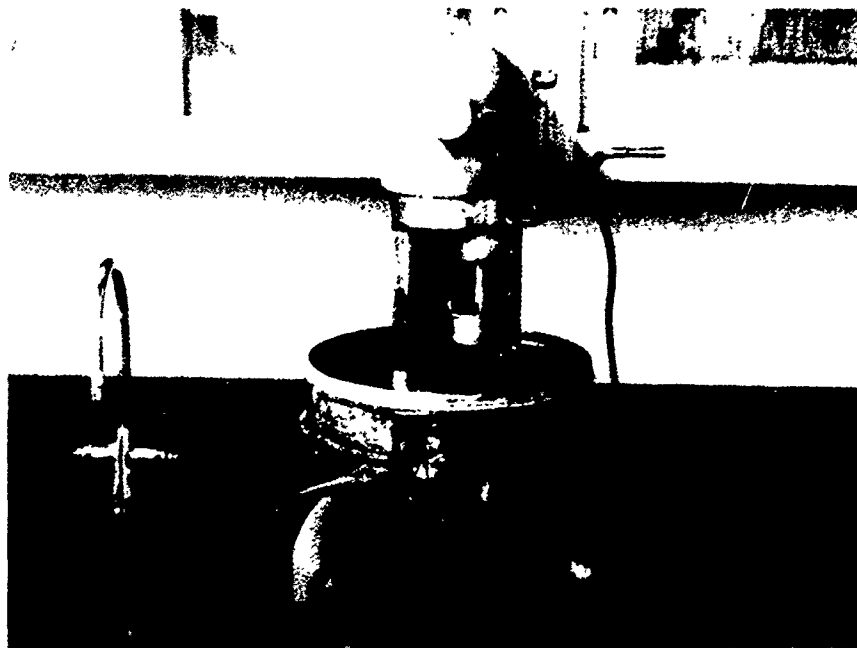


Figure 5. Abrasion Test Device.

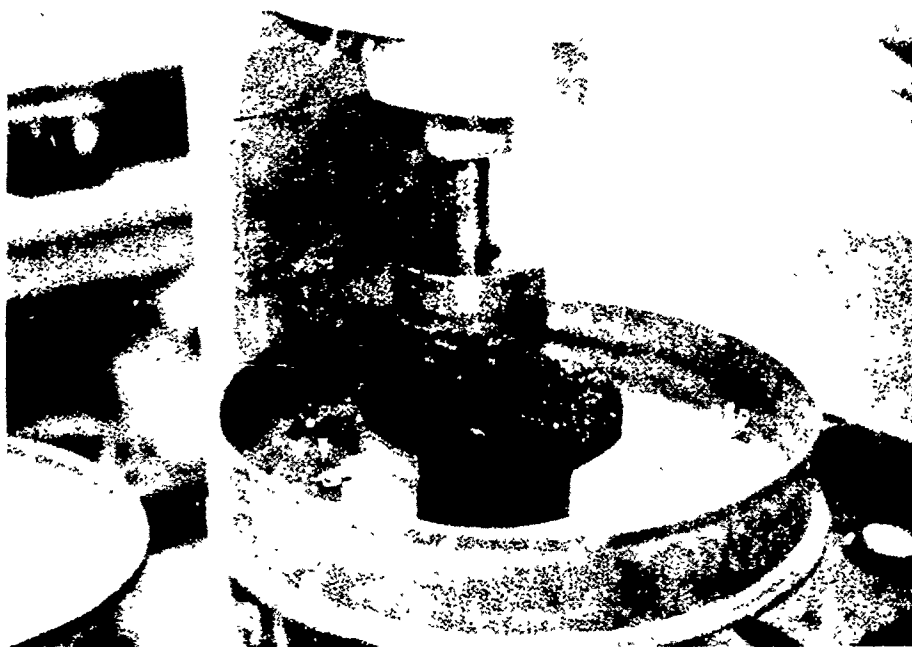


Figure 6. Closeup of Abrasion Test Device.

TABLE 3. EVALUATION OF MATERIALS AS FIRE-RESISTANT PFS COATINGS

Product	Mixture	Sample No.	Date Coated	Weight grams			Permeability milliliters per minute			Remarks ^a
				Original Specimen	After Coating	After Fuel	Before Coating	After Coating	After Abrasion	
Asphalt control	Not treated	1	10/80	1662.8	--	1420.0	3765	--	--	Failed during abrasion
		2	12/80	1931.0	--	1914.2	--	--	--	Failed during abrasion
A	1 part A to 5 parts B	1	10/80	--	--	--	2031	1342	--	Light coat
		2	10/80	--	--	--	2616	1696	--	Heavy coat
		3	12/80	--	1800.2	1803.2	2490	1331	867	Cured for 14 days
		4	1/81	1625.7	1638.9	--	3765	2573	1009	Cured for 5 days
		5	2/81	--	2056.0	2080.0	2058	1235	1087	
C	1 part binder to 2 parts activator	1	10/80	--	--	--	2807	None	--	Diluted with 15 percent acetone
D	1 part binder to 2 parts activator	1	12/80	--	1842.0	1839.3	2757	1169	1103	
		2	1/81	1613.2	1627.8	--	2304	1331	821	
		3	2/81	--	2046.0	2073.0	3027	1470	2304	Abraded immediately after fuel test
E	2 component 50-50 mix 2 thru 4 thinned with 10 percent acetone	1	10/80	--	--	--	2086	None	--	
		2	10/80	--	--	--	2205	1642	--	Unknown error, mixture did not cure (violent high heat reaction when mixed)
		3	10/80	--	--	--	1696	None	--	Did not run fuel-drip test
		4	12/80	--	1843.9	--	1979	234	--	
F	1 part emulsion to 1 part water	1	10/80	--	--	--	1678	651	--	Asphalt washed from surface aggregate
		2	10/80	1368.5	1371.0	--	2662	1111	--	
G	1 part emulsion to 1 part water	1	10/80	--	--	--	2205	1625	--	
H	4 parts A to 10 parts B	1	10/80	--	--	--	2304	924	--	Too thick, resulted in low permeability
I	28 parts water to 100 parts emulsion	1	10/80	--	--	--	2174	--	--	Asphalt washed from surface aggregate
K	1 and 2, no dilution 3 thru 6, 2 parts water to 3 parts emulsion	1	10/80	--	--	--	2058	1484	--	
		2	12/80	--	1864.8	1858.5	1860	578	--	Not cured after 4 days
		3	12/80	--	1743.8	1734.8	2490	1152	--	Asphalt washed from specimens
		4	1/81	--	2007.0	2032.0	2490	812	1029	
		5	1/81	1613.8	1627.8	--	2573	1215	1245	
		6	2/81	1621.8	1633.5	--	3027	2205	2531	

(Continued)

^aAll products cured a minimum of 24 hours, in most cases for several days.

TABLE 3. EVALUATION OF MATERIALS AS FIRE-RESISTANT PPS COATINGS (CONCLUDED)

Product	Mixture	Sample No.	Date Coated	Original Specimen	Weight grams		After Fuel	After Abrasion	Permeability milliliters per minute				Remarks
					Before Coating	After Coating			Before Coating	After Coating	Before Coating	After Abrasion	
L	1 part thinner to 3 parts binder	1	10/80	--	--	--	--	--	1331	--	--	--	Fuel dissolved asphalt from specimen
		2	12/80	--	1783.1	1791.5	--	1787.5	1979	1029	--	--	
		3	1/81	1639.2	1653.7	--	--	1639.2	2237	1276	1342	--	
		4	2/81	--	1912.0	1933.5	--	1926.0	2031	1235	1036	--	
M	Not diluted	1	9/80	--	--	--	--	--	2859	784	--	--	Fuel dissolved asphalt from specimen
		2	10/80	1448.7	1452.4	--	--	--	2662	1883	--	--	
		3	12/80	--	1571.8	1549.7	--	1422.0	2144	1591	--	--	
N	No. 4 diluted with 20 percent water, remaining not diluted	1	10/80	--	--	--	--	--	1470	--	--	--	Not cured completely, even after 7 days of curing, material flushed from specimens during permeability test
		2	10/80	1530.0	1542.8	--	--	--	3087	742	--	--	
		3	12/80	--	1799.2	1800.8	--	1798.6	2144	735	--	--	
		4	2/81	1631.2	1645.0	--	--	1645.2	2115	1331	1143	--	
		5	2/81	--	1994.5	2020.0	--	2019.0	2205	698	649	--	
O	Not diluted	1	10/80	--	--	--	--	--	1319	409	--	--	Fuel dissolved asphalt from specimen
		2	2/81	1623.3	1637.5	--	--	1626.3	2708	1416	858	--	
		3	3/81	--	2085.0	2116.0	--	2108.0	3859	1860	1715	--	
P	Not diluted	1	10/80	--	--	--	--	--	2375	844	--	--	Fuel dissolved asphalt from specimen
		2	10/80	1462.3	1465.5	--	--	--	1795	1416	--	--	
		3	12/80	--	1561.7	1568.2	--	1562.8	2058	625	--	--	
		4	2/81	1618.8	1634.4	--	--	1627.8	2573	1331	953	--	
		5	2/81	1745.0	--	1775.0	--	1767.0	2115	560	1276	--	

2. Specimen Preparation

The test specimen evolved through three different types and sizes to the final specimen types as indicated below:

- Type 1 A 4-inch-diameter specimen with a 3/4-inch thick PFS cap on a 2-inch thick asphalt concrete base
- Type 2 A 6-inch-diameter specimen with a 3/4-inch thick PFS cap on a 2-inch thick asphalt concrete base
- Type 3 A 6-inch-diameter specimen with a 3/4-inch thick PFS cap on a 1-inch thick concrete base

The Type 1, 4-inch specimens, used in an initial screening of the products, were enlarged to 6 inches (Type 2) to facilitate the use of the developed abrasion test. Finally, a concrete base for the specimens was adopted for Type 3 to enable weight loss measurements after fuel tests by eliminating the problem of asphalt loss from the base caused by the fuel. Type 3 specimens were used for the data shown in Tables 3 and 4.

The PFS caps were prepared by heating the aggregate and binder (6.5 percent by total weight, AC-20) to $290^{\circ}\text{F} \pm 5^{\circ}$ and compacting the mixture at $250^{\circ}\text{F} \pm 5^{\circ}$. The PFS caps were compacted on previously prepared base cores composed of asphalt or portland cement concrete.

3. Compaction Methods

The 4-inch specimens were compacted in molds by using 10 blows of a standard Marshall compaction hammer (Reference 6). For all 6-inch specimens a gyratory compactor (Reference 7) was used. The gyratory compaction procedure consisted of 10 revolutions at a 1-degree angle of gyration and a 200-psi foot pressure setting (see Figure 7).

4. Coating Procedure

All materials were applied to the PFS caps with a 1-inch nylon brush. A method for spraying the materials would have been preferred, but the products varied so widely that spraying the surfaces of the PFS in the laboratory was impractical. Brushing was the simplest method found to apply the correct amounts of the various products. The entire surfaces and edges of the PFS were covered with material, and in several instances the material flowed through the PFS and out along the edges of the specimen. An estimate of the application rate was made by dividing the total weight of material used by the total surface area of the specimen covered. The amounts used equate to application rates ranging from approximately 0.05 to 0.1 gallons per square yard (gal/sq yd). When an emulsion was used, the PFS was dampened to aid in proper coating. Products B and J, which required heating for application, could not be readily applied as coatings to PFS pavements with a brush because they cooled quickly upon contact with the brush and the PFS surface, making proper application difficult. The spraying of thin coats of these materials in the field could be performed with a bituminous distributor.

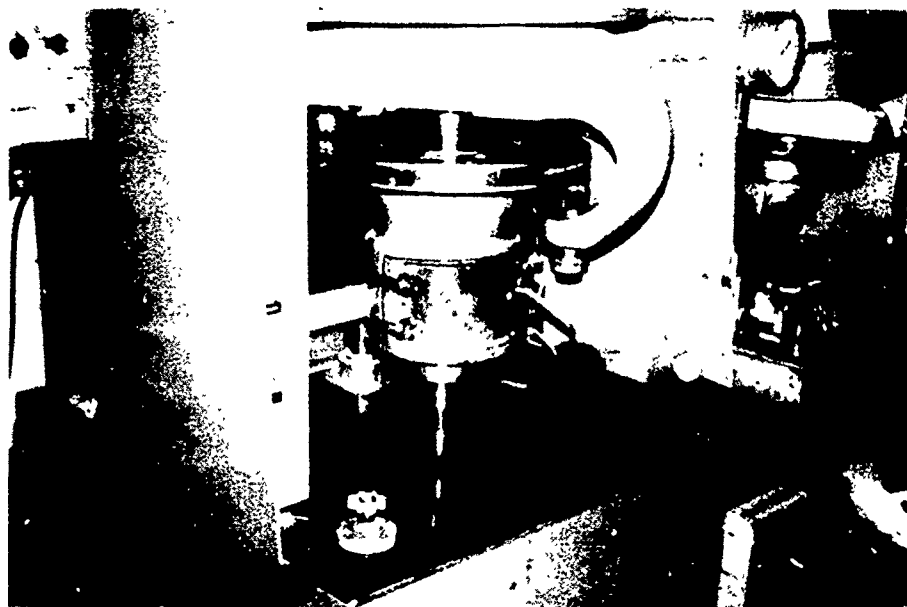


Figure 7. Gyratory Compaction Machine.

5. Curing

All materials were allowed to cure to a tack-free surface condition, and in no case were materials allowed to cure for less than 24 hours prior to testing. The materials and PFS specimens were maintained at an ambient laboratory temperature of $70^{\circ}\text{F} \pm 10^{\circ}$ during application and subsequent cure periods.

6. Initial Screening

During development of tests and procedures to be used in both phases of laboratory testing, an initial screening of products was performed. These tests were used primarily to evaluate the fuel-resistance capabilities of the products and to become acquainted with any problems in their preparation and application. The products were prepared according to manufacturers' recommendations and applied as coatings to 4-inch-diameter PFS specimen cores. Permeability of the test specimens was measured to insure that the coated samples maintained satisfactory permeability. Any product which caused the permeability to fall below 1000 milliliters per minute (ml/min) (Reference 1) was considered unacceptable as a coating. Permeability of the samples was measured before and after the coating application as well as after the abrasion test. For these initial tests the specimens were subjected to a fuel-drip of 1000 milliliters of fuel (Reference Fuel B) and evaluated visually for damage caused by the dripping fuel. The specimens which performed well in these drip tests were then subjected to the hydraulic fluid test.

7. Results of Initial Screening

The products tested covered a wide range of material types and varied greatly in effectiveness (Table 3). Several of the products were eliminated

as possible satisfactory coatings because they could not be applied to the PFS cores without decreasing the permeability in the specimens to an unacceptable level. These products were later tested as potential PFS binders if they exhibited satisfactory fuel-resistance properties (See Table 4). The results of the tests on coated samples subjected to hydraulic fluid demonstrated that the products which resisted damage from the jet fuel also resisted damage from the hydraulic fluid. The primary requirements for these products to be considered successful were that they be resistant to the damaging effects of both jet fuel and hydraulic fluid and that the permeability remain satisfactory. Therefore, it was decided to simplify the testing required by performing laboratory tests using only jet fuel and then to make cursory compliance tests with hydraulic fluid on the products which demonstrated the greatest fuel resistance. The results shown in Tables 3 and 4 were obtained using Reference Fuel B only.

8. Test Results

The amount of thickness of coating applied was kept to a minimum in order to maintain the specimens' permeability. If any part of the PFS was not completely coated the fuel was allowed to enter, to get beneath the coating, and to destroy the PFS. Table 3 lists the product mixtures used and the test values determined. Products B and J were not tested as coatings because they could not be properly applied to the specimens.

Product A was a two-part, water-soluble, epoxy resin mixed at a ratio of 100 parts A to 495 parts B by weight. The initial and later testing showed that no thinning of the mix was required for coating. The fuel-drip tests removed some surface asphalt and left the PFS surfaces tacky. After the abrasion tests the specimens remained tacky, but the PFS was not damaged.

Product C was a two-part coal-tar epoxy mixed at a ratio of 1 part binder to 2 parts activator by weight. This material was too viscous and severely reduced the permeability of the PFS. The manufacturer had no suitable method to reduce the viscosity, and testing of this product as a coating was eventually discontinued.

Product D, a two-part coal-tar epoxy, was produced by the same manufacturer as Product C. The mix ratio was 1 part binder to 2 parts activator by weight. This product was provided by the manufacturer after he was informed that initial testing showed that Product C was too viscous for coating requirements. Product D was thin enough to properly coat the PFS cap, and all specimens coated retained the required minimum permeability of 1000 ml/min. The fuel test removed some surface asphalt and left the surface very tacky. The abrasion test removed some surface asphalt where the hose abraded the specimen surface (see Figures 8, 9).

Product E was a two-part coal-tar epoxy mixed at a ratio of 1 part base to 1 part hardener by volume. This material was too viscous to flow through the voids of the PFS, and it greatly reduced the permeability of the specimen. Attempts to reduce the viscosity of the material with various percentages of acetone (up to 10 percent by volume, as suggested by the manufacturer) failed to achieve the necessary viscosity to allow even application.

TABLE 4. EVALUATION OF MATERIALS AS FUEL-RESISTANT PFS BINDERS.

Product	Mixture	Sam- ple No.	Percent Binder Material Percent Total Weight	Con- crete Base	Weight grams			Permeability milliliters per minute				Date Con- structed	Remarks
					Original Specimen	After Fuel	After Abrasion ^a	Before Fuel	After Fuel	After Abrasion			
A	1 part A to 5 parts B	1 2 3	5 b ₇ 10	1025.9 1065.6 1024.9	1692.2 Void 1709.8	1687.1 -- 1699.0	1233.1 -- 1681.6	4678 -- 4411	4824 -- 4540	-- -- 3356	5/81 5/81 5/81	Damaged specimen, not related to testing	
B	14.6 parts A to 85.4 parts B	1 2	5 7	1171.6 1145.1	1860.0 1838.1	1854.7 1829.6	1854.9 1823.4	3675 3675	2490 1895	-- --	8/81 8/81	Part of base chipped off	
C	1 part binder to 2 parts activator	1 2 3	5 7 10	1072.6 1030.6 1042.6	1761.2 1734.4 1758.9	1858.1 1730.0 1759.6	1759.2 1731.8 1761.4	4824 4678 4062	5513 5513 4288	4288 4824 3675	5/81 5/81 5/81		
E	1 part base to 1 part hardener	1 2 3	5 7 10	1097.3 1015.4 1085.5	1774.9 1720.4 1807.1	1766.9 1721.4 1810.4	1243.9 1725.2 1814.3	4824 5513 3859	4540 4288 2969	-- 3675 2859	5/81 5/81 5/81	Failed during abrasion, insufficient binder	
F	Not diluted	1	5	1253.3	1931.7	--	--	5513	--	--	5/81	Failed during fuel drip test, in sufficient binder	
G	Not diluted	1 2	7 10	1125.1 1012.0	1820.2 1714.1	1813.0 1704.8	1605.6 1683.5	5937 4824	4824	-- 5513	5/81 5/81	Failed during abrasion test	
H	4 parts hardener to 10 parts resin	1 2 3	5 7 10	1008.3 1063.6 1099.1	1702.5 1777.0 1797.9	1601.5 1764.1 1797.0	-- -- 1800.2	4678 5146 5513	5937 5513 4824	-- -- 5513	5/81 5/81 5/81		
I	Not diluted	1 2	7 10	1248.7 1121.3	1941.2 1829.5	-- 1800.7	-- --	5513 3675	-- 3675	-- --	8/81 8/81		
J	Heated to 225 deg F	1 2 3	5 7 12	1132.6 1050.0 1059.2	1827.8 1757.5 1734.4	1814.9 1747.0 1723.1	1817.5 1750.0 1241.6	4824 3508 5937	5513 4824 5937	-- -- --	8/81 8/81 5/81	Failed during abrasion test	
K	Not diluted	1 2 3	7.5 10 12	1139.0 1033.3 1197.1	1834.4 1730.2 1863.9	1813.3 1714.2 1863.6	1136.1 1173.5 1861.8	2708 2339 5513	2412 2412 5513	-- -- 5513	5/81 5/81 5/81		
L	1 part thinner to 3 parts binder	1 2	7 10	1051.1 1172.3	1709.4 1839.0	1709.3 1844.7	c 1839.4	d 5513	d 4824	d 4288	5/81 5/81		
O	2 parts adhesive to 1 part acetone	1 2	7 10	1103.8 1117.9	1779.7 1783.8	1782.1 1789.6	1781.1 1786.7	3216 4288	4824 4824	2757 3675	5/81 5/81		
P	2 parts adhesive to 1 part acetone	1 2	7 10	1147.8 1172.3	1824.6 1839.0	1831.2 1844.7	1817.0 1839.4	4540 5513	5513 4288	5937 4288	5/81 5/81		

^a Final weight, obtained by allowing weight to stabilize over several days.^b Over optimum.^c Reason for no weight measurement, damage to specimen unrelated to testing.^d High permeability, could not establish required water head with given water pump.



Figure 8. Product D, After Coating but Before Testing.



Figure 9. Product D, After Fuel-Drip and Testing.

Due to the difficulty in attaining thin application of this material, testing was discontinued, even though when tested in the initial test series, it did exhibit good fuel-resistant qualities.

Product F, a coal-tar emulsion with approximately 3 percent rubber added, was diluted with an equal amount of water by volume to achieve a viscosity at which the material could be easily applied. During the fuel-drip test conducted initially, the asphalt was dissolved from the PFS, and pieces of aggregate became loose and could be easily removed by hand. The material was eliminated from further testing because, when it was applied in amounts which allowed for satisfactory permeability, the PFS cap was not resistant to fuel.

Product G, a coal-tar emulsion with approximately 0.8 percent rubber added, was diluted with an equal amount of water by volume. This product performed similarly to Product F during the drip test, failed to exhibit satisfactory fuel-resistant properties, and was dropped from further testing.

Product H was an epoxy resin with a mix ratio of 4 parts hardener to 10 parts resin by weight. The initial testing showed that this mixture was too viscous to be evenly spread over the PFS, and the manufacturer could not supply a method to reduce the viscosity of the material. Because of the viscosity problem the material was discontinued from further testing as a coating.

Product I was a coal-tar emulsion. When this material was received, some separation of the tar and water had occurred. Thorough mixing significantly reduced settlement of tar from the emulsion, but total elimination was impossible. The emulsion was diluted with approximately 25 percent water by volume to achieve the desired viscosity. During initial fuel-drip testing, the surface aggregate was washed clean by the fuel; hence, testing of this product was discontinued due to its lack of fuel resistance.

Product K, a coal-tar pitch emulsion, was diluted at two different water contents. Two specimens were originally coated with the undiluted product, but eventually a mixture of 2 parts water to 3 parts emulsion was selected for testing because this was the minimum rate of dilution at which the PFS attained the required permeability. At this proportion, only one specimen from later testing experienced a permeability below the 1000 ml/min minimum. During the initial testing, as well as during the later tests, the fuel from the fuel-drip test dissolved some of the surface asphalt and made the surface tacky. When the specimens were abraded, the asphalt coating the aggregate under the abrasion hose was completely removed (see Figures 10, 11).

Product L, a two-part rubberized sealant, was mixed at a ratio of 3 parts binder (A) to 1 part thinner (B) by weight. This material was easily applied and appeared to successfully coat the PFS caps. The permeabilities of the coated specimens were above the recommended minimum. The fuel-drip test did not remove any surface asphalt from the specimens, although it did produce a slightly tacky surface. Abrasion tests removed a small amount of surface asphalt but caused no other damage.

Product M was a combination of asphalt and plastic in an emulsion form. This emulsion was diluted with varying amounts of water ranging from



Figure 10. Product K, After Coating but Before Testing.

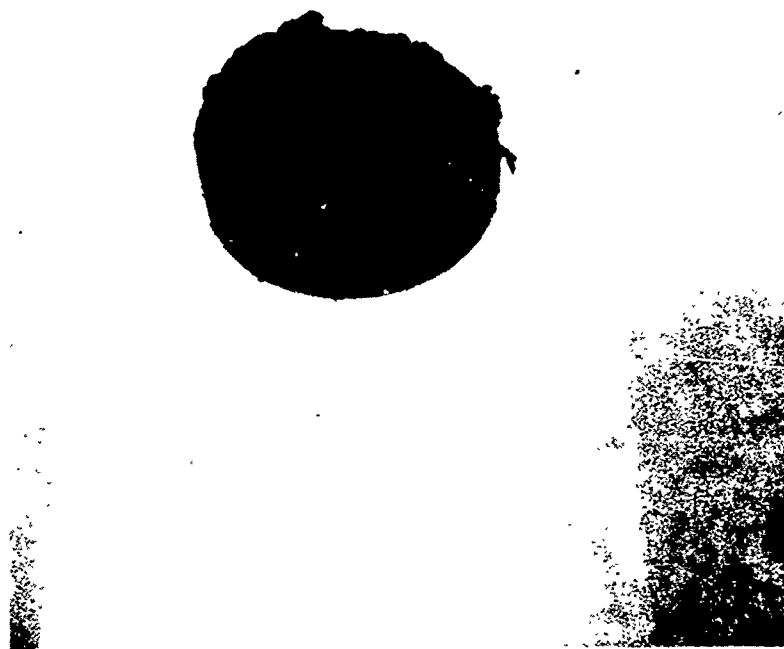


Figure 11. Product K, After Fuel-Drip and Abrasion Testing.

none to a 1 to 1 mixture by volume. The PFS sealed with this product was measured to have the recommended permeability, provided the sealer was diluted with 50 percent or more water. During initial testing, the curing time was less than 24 hours, except for the 1 to 1 mixture which required several days to cure. Asphalt was washed from the specimens when fuel was dripped on them. Also, the specimens lost aggregate from the PFS during the abrasion test.

Product N was a water-soluble polyvinyl acetate material, usually applied at full strength, while one specimen was applied with 20 percent water added during later coating tests. When applied with 20 percent water dilution, the polyvinyl acetate properly coated the PFS specimen and provided the required permeability. It was observed in all specimens that while the surface material cured, the polyvinyl acetate which penetrated the PFS did not cure. From the outside the material appeared to cure; however, when the PFS specimen was placed on its side, the coating material flowed out of the core. The material continued to flow whenever the specimen was moved as long as 2 weeks after application. When permeability tests were performed, the flushing of the uncured product N caused the water to discolor. This flushing reduced the reliability of the permeability test results. Although the material had demonstrated a limited fuel resistance, it was dropped from further testing because of the curing problems.

Product O was a nitrile rubber-based adhesive. In the initial screening test the material was too viscous and required dilution to insure satisfactory coating. It was then diluted at a rate of 2 parts acetone to 3 parts adhesive by weight for the remainder of the tests. At this dilution ratio the material properly coated the PFS, and the specimen retained the recommended permeability. The fuel-drip test did not damage the coated PFS surface, and there was no evidence of any material washing away. The abrasion test had no effect on the PFS.

Product P was a nitrile rubber-based adhesive. Initial screening tests showed it to be too viscous and too thick to insure satisfactory coating. Acetone was used to dilute the adhesive at a rate of 1 part acetone to 2 parts adhesive by weight. This mixture produced a satisfactory coating for the PFS and allowed the specimen to retain the minimum recommended permeability. Neither the fuel-drip test nor the abrasion test which followed it caused any damage to the PFS.

In summary, materials A, D, L, O, and P performed satisfactorily as coatings when subjected to fuel spillage and abrasion tests.

D. POROUS FRICTION SURFACE BINDERS

1. Material Preparation

The materials, when evaluated as binders, were prepared according to manufacturers' specifications (see Table 4).

2. Specimen Preparation

The specimens for the binder test were constructed with 3/4-inch PFS caps on 1-inch-thick, 6-inch-diameter portland cement concrete cores as used

for the Type 3 specimens in the coatings test phase. The compaction of the PFS caps was performed as described earlier.

3. Curing

All specimens were allowed to cure for a minimum of 24 hours before testing. The PFS specimens made with these special binders were maintained at an ambient laboratory temperature of $70^{\circ}\text{F} \pm 10^{\circ}$ during construction (except when not applicable) and subsequent cure periods.

4. Binder Content

PFS caps were constructed with the various materials at different binder contents to determine the optimum percentage of binder by total weight of mix. One criterion used for this determination was a visual examination of the amount of binder needed to bind the PFS specimen aggregate without excess bleeding. With every material tested, a convenient percentage of binder was selected as a starting point (usually 7 percent), and this percentage was increased/decreased as required. The other criterion used was a requirement that the permeability remain above the recommended minimum of 1000 ml/min.

5. Tests

Three of the products (D, M, and N) tested as coatings were eliminated from the binder tests due to their lack of resistance to the adverse effects of fuel. Permeability and weight measurements were taken throughout the testing to evaluate each product's effectiveness in resisting fuel.

6. Results

The optimum content for the majority of the materials tested was between 7 and 10 percent by total weight of mix. The percentages of binder added by weight of total mix varied from 5 to 12 percent for the different materials. In all cases, with the gradation used, the optimum binder content was exceeded (evidenced by bleeding) before the permeability fell below the recommended limit of 1000 ml/min.

Product A was tested at binder contents of 5, 7, and 10 percent by weight, with the optimum occurring between 7 and 10 percent. Slight bleeding of the binder occurred at 10 percent, although the permeability remained high. The material did not appear to perform as well as it did in the coating testing. The specimens showed signs of binder loss during the fuel test, and the PFS was softened. The aggregate could be moved by hand immediately after the fuel test. During the abrasion test more binder material was lost, and some small pieces of aggregate were lost from the PFS.

Product B was tested at binder contents of 5 and 7 percent, with the optimum content appearing to be approximately 7 percent by weight of total mix. The mixtures performed well at both binder contents as indicated by minimal weight loss from the fuel and abrasion tests.

Product C was tested at binder contents of 5, 7, and 10 percent, with the optimum content appearing to be approximately 10 percent by weight of total mix. Minimal damage to the PFS was caused by the fuel and abrasion tests. The only visible damage was a slight scuffing caused by the abrasion head. On all specimens the permeability increased after the fuel test but then fell slightly below the original permeability after the abrasion test.

Product D was not tested as a binder.

Product E was tested at binder contents of 5, 7, and 10 percent by weight of total mix, with the optimum judged to be between 7 and 10 percent. At 5 percent there appeared to be insufficient binder present, which resulted in the specimen falling apart during the abrasion test. The fuel test made the surface of all the specimens tacky, and, after the abrasion test, the specimens (except for the one with 5-percent binder) recorded a slight weight increase (less than $1/2$ of 1 percent). The permeability of the specimens decreased after both the fuel-drip and abrasion tests, although it remained well above the required minimum. Product F was prepared at binder contents of 5, 7, and 10 percent by weight of total mix. The specimens with the highest binder content (10 percent) lost the smallest amount of aggregate after the fuel and abrasion tests. A slight drainage of binder from the 10 percent specimen illustrated that this specimen was near the optimum binder content. All specimens showed a loss of binder shortly after starting of the fuel-drip test. The permeability generally increased during testing as the specimens continued to lose aggregate (see Figures 12, 13).

Product G was tested at contents of 7 and 10 percent by weight of total mix. The optimum content appeared to be approximately 10 percent. The specimen at 10-percent binder showed loss of binder and some aggregate after the fuel test, while the specimen at 7 percent had a larger amount of aggregate dislodged. The permeability of the test specimens increased after the fuel tests. Both specimens were damaged during the abrasion test.

Product H was prepared at binder contents of 7 and 10 percent by weight of total mix. During the tests the permeability of the specimens remained generally constant. The surface of the specimens became tacky after the fuel-drip test. As with Product E, the specimens showed a slight final weight gain after the fuel and abrasion tests. The specimen at 7 percent binder was effectively destroyed during the fuel test, and the one at 10 percent was also damaged.

Product I was mixed at binder contents of 7 and 10 percent, with slight bleeding occurring at the 10-percent content. The fuel test removed some binder and aggregate from the PFS, and more aggregate was dislodged later during the abrasion test.

Product J, a paving-grade road tar, was mixed at 225°F to produce the PFS specimens. From the two specimens constructed it appears that the optimum binder content lies between 5 and 7 percent by weight of total mix. The fuel-drip test removed some binder from the PFS and softened the surface. The specimen lost weight from the fuel test; however, the specimens still showed a slight weight gain after the abrasion test. This weight gain was apparently caused by fuel softening the binder and displacement of the binder

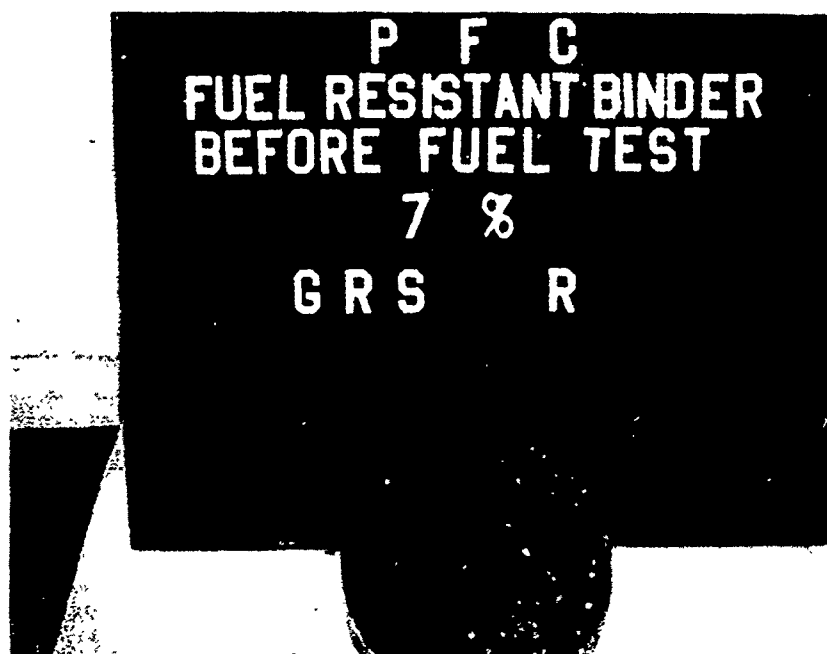


Figure 12. Product F, Before Testing.

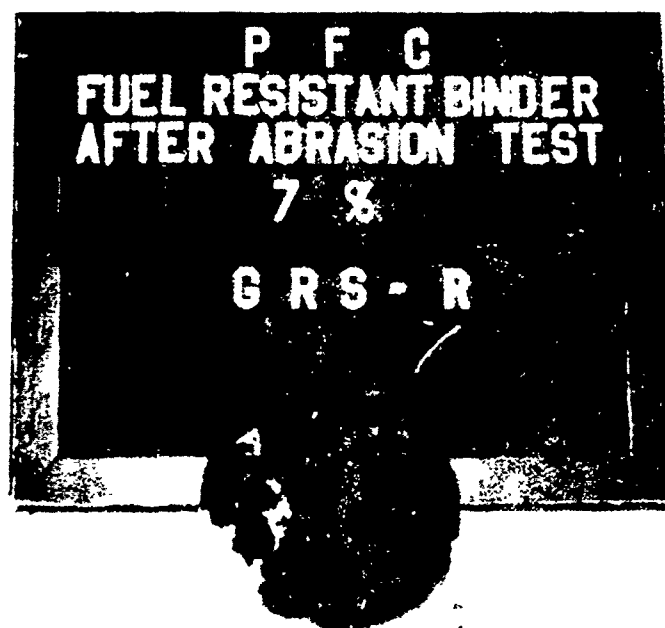


Figure 13. Product F, After Testing.

and/or aggregate during the abrasion test with the fuel and water present being trapped in the PFS specimen. The permeability of the specimens showed a small increase after each test (see Figures 14, 15).

Product K was constructed at 7.5, 10, and 12 percent by weight of total mix. These showed the optimum content to be approximately 10 percent, due to some bleeding of material in the specimen with 12 percent emulsion. The fuel-drip test dissolved some of the emulsion from the PFS surface. The aggregate, loosened by the fuel, was dislodged during the abrasion test on all three specimens, and the specimens were destroyed before the test was completed. The permeability was not affected by the fuel-drip test; however, the permeability could not be measured after the abrasion test due to the samples falling apart.

Product L was produced at binder contents of 7 and 10 percent of total mix. The permeability of both specimens remained higher than the equipment could measure throughout the testing. The fuel-drip and abrasion tests had little effect on the specimens. The weight of the specimens before and after the fuel-drip and abrasion tests remained nearly constant.

Product M was not included in the binder testing because of poor results when evaluated as a coating.

Product N was not included in the binder testing because of poor results when evaluated as a coating.

Product O was prepared at binder contents of 7 and 10 percent. After the fuel-drip test the surface of the PFS was tacky, and some of the surface binder was displaced during the abrasion test. The specimens showed no appreciable change in weight at the end of all testing, while the permeability decreased slightly.

Product P was prepared at binder contents of 7 and 10 percent. The fuel and abrasion tests removed some binder from the specimens. The specimens showed a slight weight gain after the fuel test but suffered a weight loss during the abrasion test. The permeability of the specimen after the fuel-drip and abrasion tests remained above the minimum recommended value of 1000 ml/min.

In summary, materials which performed satisfactorily as binders when subjected to fuel spillage and abrasion were B, C, E, J, L, O, and P. Materials which performed satisfactorily as binders and sealers were L, O, and P.

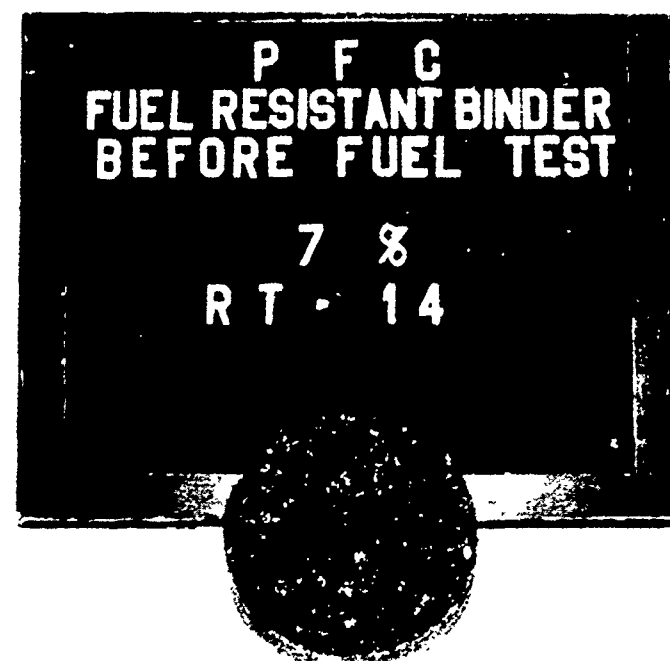


Figure 14. Product J, Before Testing.

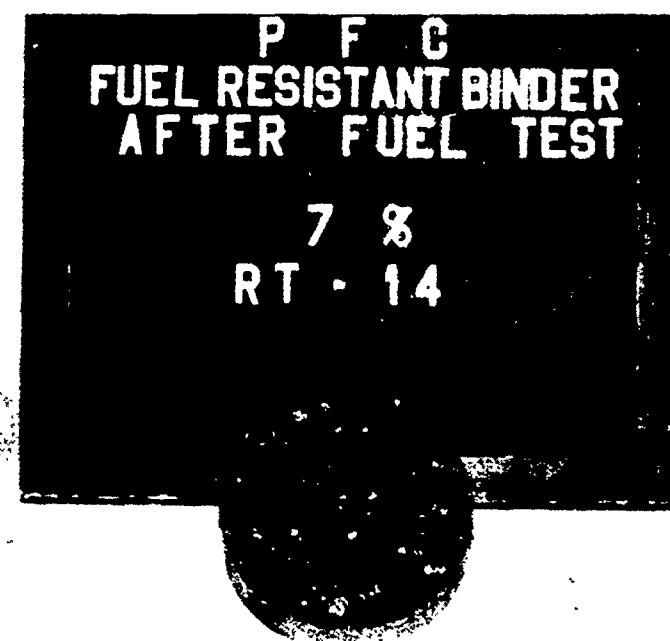


Figure 15. Product J, After Testing.

SECTION IV

FIELD TEST STUDY

An RT-14 road tar, Product J in the laboratory study, was evaluated in the field for its fuel-resistant effectiveness when subjected to jet fuel (JP-4), hydraulic fluid, and F-4 load traffic. Product J, which performed satisfactorily in the laboratory study as a binder, was selected because of its low cost and its past use in dense graded mixtures. A test strip was constructed with RT-14 as the binder, and a control section was constructed with AC-20 asphalt cement as the binder (see Figure 16). These sections were exposed to fuel and hydraulic fluid spillage and subjected to simulated F-4 traffic.

A. MATERIALS

1. Aggregate

The aggregate used for producing the mixtures for the field test sections was a crushed Alabama limestone with the gradation shown in Table 4. Although this gradation contained fewer fines than required in the PFS specification, it was judged capable of fulfilling the PFS requirements of providing adequate permeability (see Figure 17).

TABLE 5. FIELD TEST PFS AGGREGATE GRADATION.

Sieve Designation (Square Openings)	Percent Passing by Weight of Total Aggregates	
	Actual	Specification Required ^a
3/4 inch	100	100
1/2 inch	98	70-100
3/8 inch	62.5	45- 75
No. 4	7.6	25- 40
No. 8	1.0	10- 20
No. 30	0.4	3- 7
No. 200	0.3	0- 5

^aCEGS-02562, Porous Friction Course for airfields and roads.

2. Binders

Two types of binders were used in the test sections; an AC-20 asphalt binder was used in one test section, while RT-14 (Product J in the laboratory study) tar binder was used in the other test section.



Figure 16. Porous Friction Surface (PFS) Test Sections, Before Fuel Spills and Traffic.

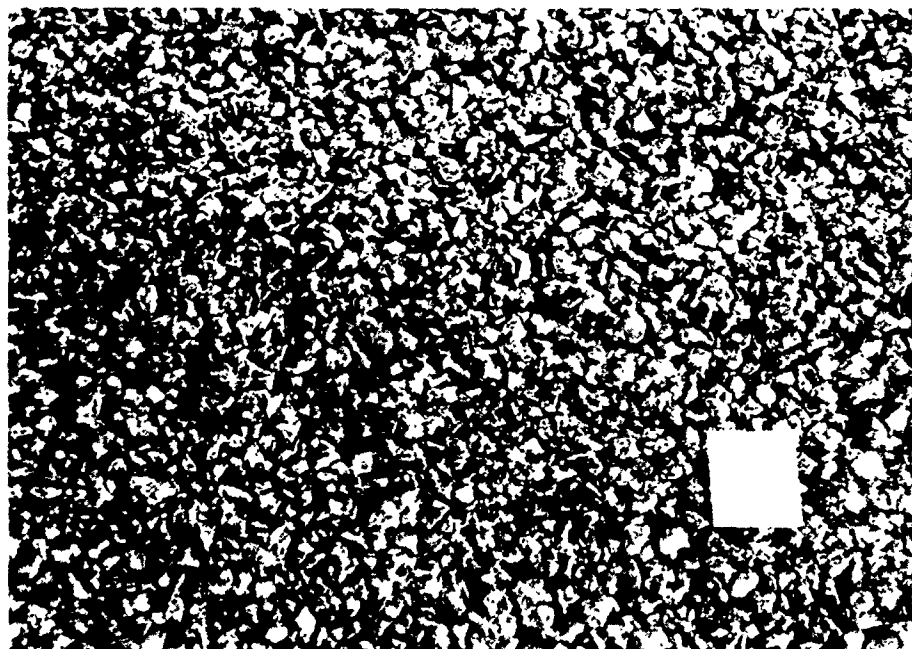


Figure 17. Surface Texture of RT-14 Tar PFS.

B. CONSTRUCTION

Figure 20 contains a diagram of the PFS test sections, giving their dimensions and the areas subjected to fuel spillage. The PFS test sections were constructed in November 1982, on a sunny day with the temperature in the high 60s. The asphalt and tar mixes were produced at a batch plant located 20 minutes from location of the test sections. The asphalt concrete in the test section area was tacked with asphalt emulsion prior to construction of the test sections (see Figure 18). The mix temperatures at the time of placement were 290°F and 240°F for the asphalt and tar, respectively. The mix was placed with a conventional paver at a 1-inch nominal depth and compacted with four passes of a steel wheel roller (see Figure 19). The asphalt and the tar test sections were the same size, 10 feet wide and 80 feet long (see Figure 20).

C. TESTING

Testing began in February 1983 after the PFS test sections had been in place for approximately 3 months. Prior to subjecting the test sections to fuel spillage, permeability tests were conducted at several locations on the PFS. The permeability was very high (greater than 5000 ml/min), which exceeded the range of the permeability measuring device. The fuel spillage tests and traffic tests were performed first on the asphalt section and then on the tar.

1. Fuel Spills

The test strip was divided in half, longitudinally, and each half was divided into four equal sections (Figure 20). The tar and asphalt test sections underwent the same testing, unless otherwise noted. Within two of the sections of the test strip (Sections 1 and 2) two 6-foot square areas were marked off and inundated with either jet fuel (JP-4), hydraulic fluid, or a combination of the two. In Section 1, test areas received only JP-4 spillage, while in Section 2 one area received hydraulic fluid and the other area a combination of both (Table 6). Section 3 was used to help determine the amount of fuel to be spilled. Three gallons of JP-4 were spilled on the AC-20 test section, and 5 gallons was tried on the RT-14 section, about 1 week before actual testing began. It was observed that 5 gallons of JP-4 would inundate an area of approximately 6 feet by 6 feet; therefore, 5 gallons and the 6-foot by 6-foot areas were used to test Sections 1 and 2. Section 4 was used as a control, while Section 3 was used to separate the spillage areas from the control. This separation was necessary to prevent excessive carry-over of fuel by the traffic wheels into the control section. Because hydraulic fluid is more viscous than JP-4, 3 gallons was selected as the amount of hydraulic fluid which would sufficiently inundate a 6-foot by 6-foot spill area.

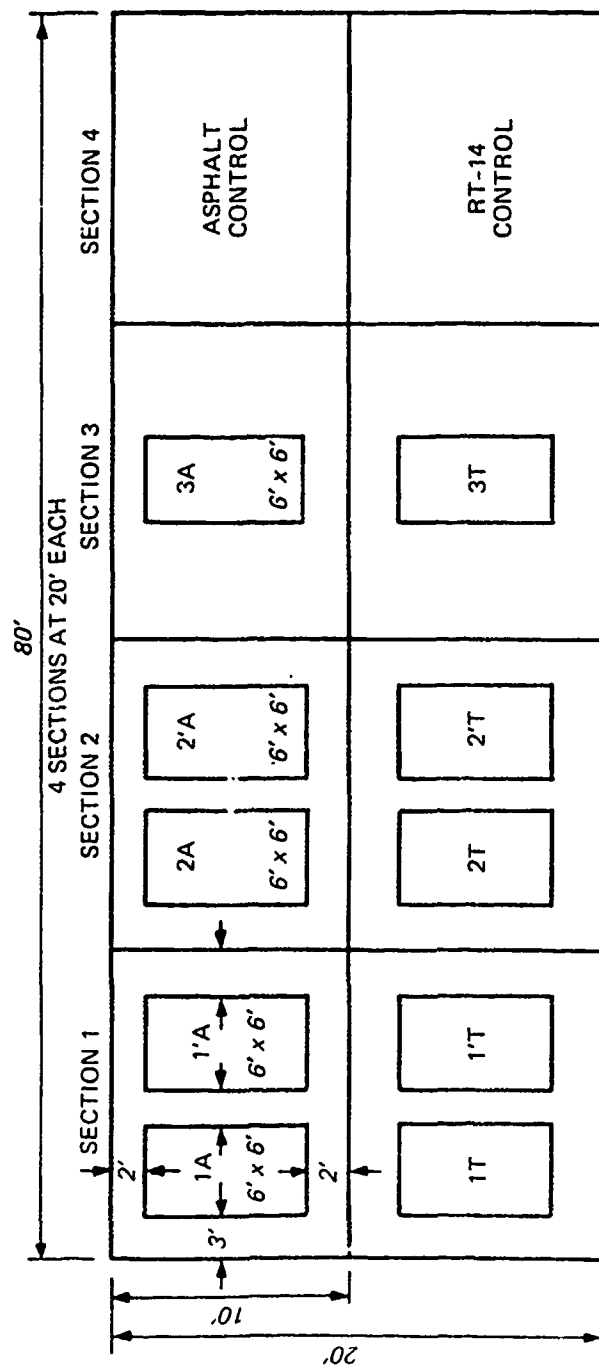
The two Sections (1 and 2) were each marked with the two 6-foot by 6-foot areas in which the spills were made. The amounts spilled and the areas where they were spilled are given in Table 6. Spills were made by filling a 5-gallon container with the desired fluid and then dumping it in the center of the 6-foot by 6-foot areas (see Figure 21). These spills were allowed to remain for approximately 10 minutes, and then they were flushed by use of a low pressure 1-1/2-inch-diameter water hose. Each spill area was flushed for approximately 5 minutes (see Figure 22). During this flow time the water



Figure 18. Placing of Tack Coat for PFS Test Sections.



Figure 19. Construction of PFS Test Sections.



1. THERE IS A SLIGHT SLOPE (< 1.0%), FROM NORTH TO SOUTH ACROSS THE TEST SECTIONS.

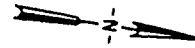


Figure 20. Layout of PFS Test Sections.

TABLE 6. FUEL SPILLAGE QUANTITIES FOR PFS TEST SECTIONS.

Area No.	Spillage Rates ^a	
	JP-4 gallons	Hydraulic Fluid gallons
1A	5	--
1T	5	--
1'A	5	--
1'T	5	--
2A	--	3
2T	--	3
2'A	5	3
2'T	5	3
3A	3	--
3T	5	--

^a Spills were accomplished by hand dumping the measured amount of fluid from a 5-gallon pail.

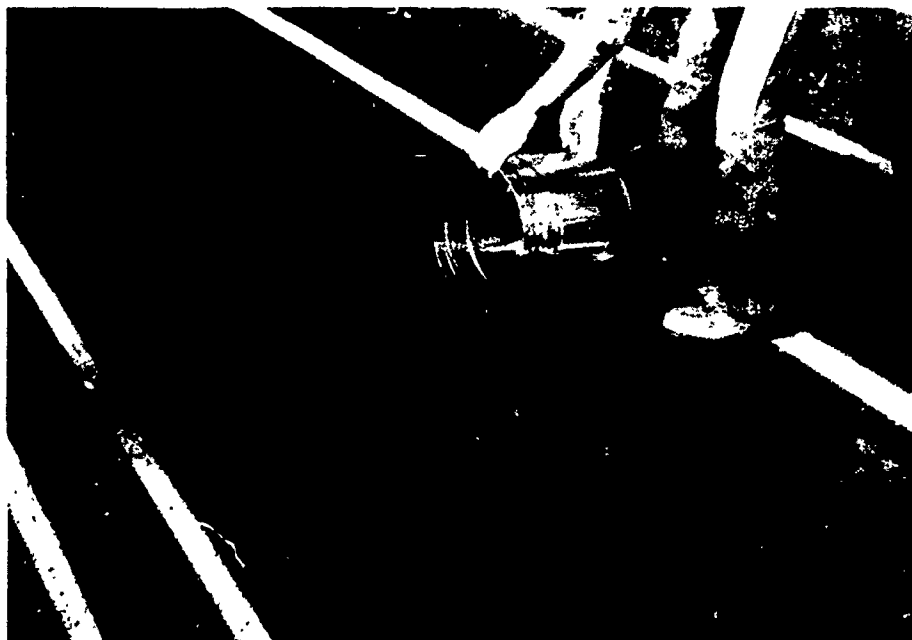


Figure 21. Spilling of Hydraulic Fluid on PFS Test Sections.

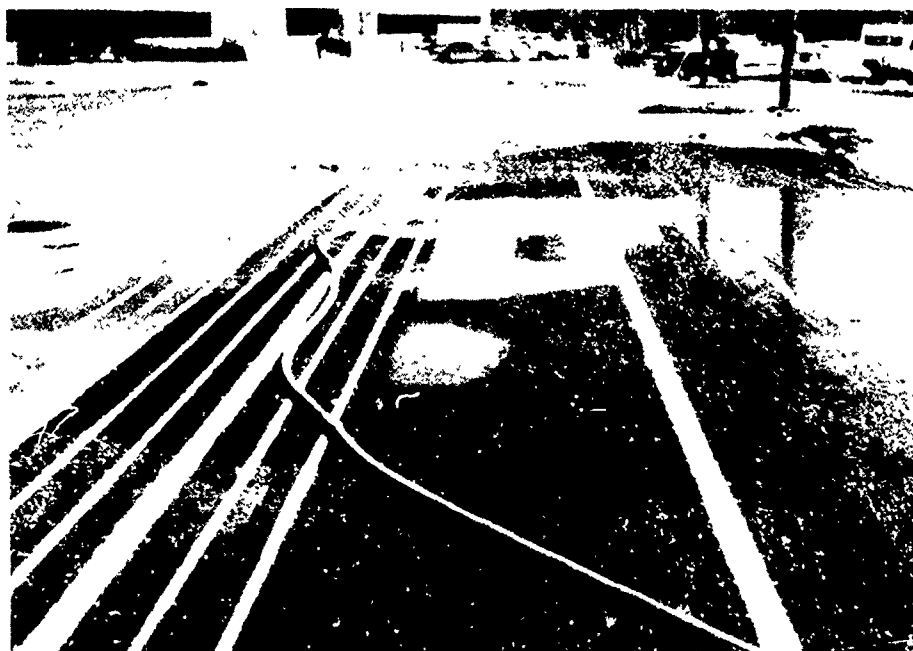


Figure 22. Flushing RE-14 Tar PFS with Low-Pressure Water Hose.

flowed through and over the PFS and removed part of the fuel. The timing and amount of water flushing were established to simulate recommended Air Force spill procedure of immediately flushing fuel spills with low-pressure water.

2. Traffic

A load cart was used to simulate F-4 traffic (see Figures 23 and 24). Traffic coverages of the spillage areas were begun approximately 30 minutes after the fuel spillage. The total traffic applied on the day of the fuel spillage was 10 coverages (one pass of the load cart over each point of the test section equals one coverage) over all PFS sections. Two days later, more F-4 traffic was applied, and, after 4 coverages were applied to the AC-20 asphalt test sections, traffic was stopped as the PFS was rutting and shoving in Sections 1, 2, and 3 (see Figure 25). Eight additional coverages (twice the coverages applied to the asphalt section) were applied to the RT-14 tar test sections without any apparent damage to the PFS. After these applications, traffic was stopped.

D. RESULTS

1. AC-20 Asphalt

After the predetermined spills were made on the asphalt PFS, ponds of asphalt and jet fuel formed along the lower edges of the test sections (see Figure 26). Stripping of the asphalt from the surface aggregate was visible. The water used to flush out the spills appeared to remove some of the fuel, but



Figure 23. Drainage from AC-20 Asphalt PFS Test Section, Approximately 30 Minutes After Testing.



Figure 24. F-4 Load Cart.



Figure 25. Rutting in Section 3 of AC-20 Asphalt
PFS Test Section.



Figure 26. Fuel Drainage Through PFS.

there was a significant amount of fuel remaining in the PFS and on the surface. This condition was even more pronounced where hydraulic fluid was spilled (see Figure 27).



Figure 27. Water-Fuel Mixture Remaining on AC-20 Asphalt PFS After Flushing JP-4 Spill with Water.

The traffic coverages on AC-20 Sections 1 and 2 immediately after flushing the fuel with water had no effect on the PFS. The only damage was in Section 3 where one week earlier 3 gallons of JP-4 had been spilled, but not flushed. This area began to ravel immediately upon being trafficked, the aggregate in the spill area was loosened, and the PFS was rutted after one coverage of traffic (see Figure 28).

Two days after the fuel spill and flushing took place the asphalt PFS received four more coverages of traffic. This time, all asphalt sections exposed to spills began to ravel and rut immediately upon the application of traffic. By inspection, before this traffic, it was noted that the aggregate in the PFS could be loosened by moving one's foot back and forth on the PFS surface.

2. RT-14 Tar

The same procedure of fuel spills and traffic used on the asphalt section was followed on the RT-14 test strip. No stripping of the aggregate or other damage was noticeable on the tar PFS after the fuel spillage. As with the asphalt PFS for the week prior to testing, the tar in Section 3 had JP-4 spilled on it. The amount was 5 gallons, as this was used in the determination of spillage amounts (see C.I., Fuel Spills). As with the asphalt PFS in Section 3, this spill was not flushed with water. The initial 10 traffic coverages had no effect on this section or on any part of the tar PFS test strip. When more traffic was applied 2 days later, the road tar PFS again performed satisfactorily (see Figure 29).



Figure 28. Raveling and Rutting of AC-20 Asphalt PFS.

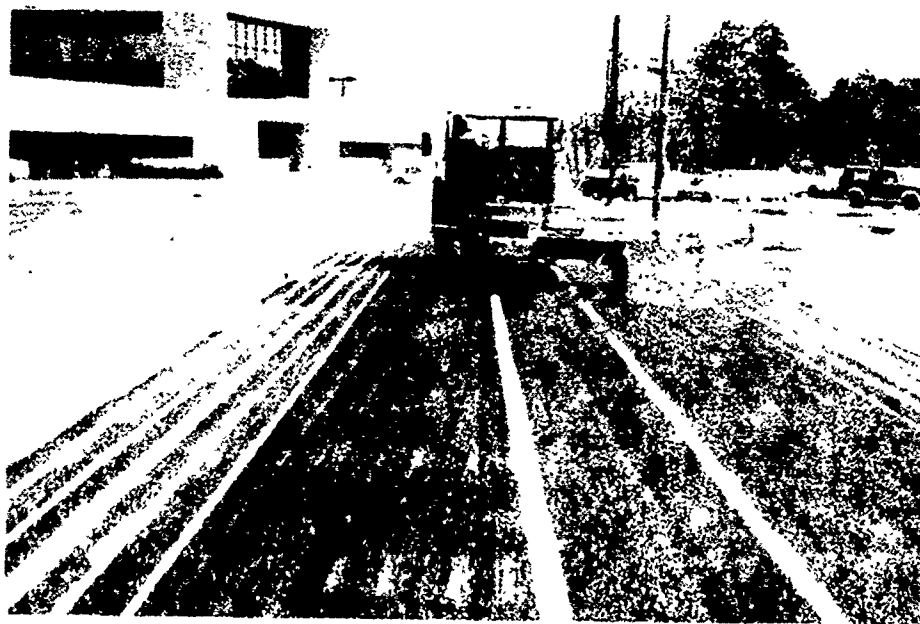


Figure 29. RT-14 Tar PFS (Left) Receiving F-4 Traffic.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The following are lists of products in decreasing order of effectiveness as fuel-resistant coatings and binders. Also included are those products which were either marginal or unsatisfactory.

FUEL-RESISTANT COATINGS

<u>Satisfactory</u> <u>Product Symbol</u>	<u>Marginal*</u> <u>Product Symbol</u>	<u>Unsatisfactory**</u> <u>Product Symbol</u>
A	F	B
L	G	C
D	I	E
O	K	H
P		J
		M
		N

FUEL-RESISTANT BINDERS

<u>Satisfactory</u> <u>Product Symbol</u>	<u>Marginal*</u> <u>Product Symbol</u>	<u>Unsatisfactory</u> <u>Product Symbol</u>
L	F	A
E	G	M
C	H	N
O	I	D
P		K
B		
J		

*Marginal includes products tested that exhibit some fuel resistance but fall below the effectiveness of the satisfactory products.

**Unsatisfactory includes products which failed or were unusable for a wide variety of reasons; see the results for individual reasons.

In the laboratory, several products appeared to have failed to protect the PFS cap because not enough material to completely coat the PFS could be applied without reducing the permeability below the recommended levels.

The relatively short pot-life of several of the materials tested (epoxies) casts doubt on their usefulness in general construction. A highly skilled and efficient group of workers would be necessary for construction due to the time

restraints. Even short-term equipment breakdowns and/or weather problems would cause wasting of the paving mix and increase PFS costs.

Product A did not perform as well as a binder as it had as a coating on a PFS. One cause for the poor performance may have been the age of the material when it was tested as a binder, or the problem may have been that the epoxy had to bind to aggregate, whereas before, as a coating, it had to bind to asphalt.

As a group, the epoxies and rubber-based mixtures performed better than the more conventional paving materials, such as the coal-tar variations, which have a history of pavement usage. Most of the exotic materials (epoxies, adhesives, etc.) tested are so expensive (\$15 to \$25 per gallon) that their usage in large quantities is economically questionable.

Under the conditions of the testing performed in the field the PFS constructed with RT-14 (Product J) as a binder performed well. It showed no adverse effects from the fuel spillage applied to it, while the asphalt PFS failed.

The results of the traffic application showed that an asphaltic PFS pavement will function for a short time (less than 2 days) after a fuel spill; however, after the fuel has had time to soften and leach out the asphalt binder the PFS begins to disintegrate under traffic. There was no softening or leaching of the binder on the RT-14 test strip.

B. RECOMMENDATIONS

It is recommended that test sections be constructed with some of the other materials investigated herein (epoxies, adhesives, etc.) to determine their performance under field conditions as coatings and/or binders.

With the increasing desire to recycle pavements, the feasibility of recycling materials containing these various binder and coating materials should be investigated.

Laying a fuel-resistant PFS over an asphalt pavement will require that the underlying pavement be protected from the fuel. It is recommended, therefore, that the materials investigated herein be examined for use as fuel-resistant seals or tack coats between a fuel-resistant PFS and the underlying pavement.

SECTION VI

REFERENCES

1. White, T. D., Porous Friction Surface Course, MP-S-75-12, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1975.
2. ASTM, Standard Practices for Design, Testing, and Construction of Slurry Seal, Designation D 3910-80a, Part 15, Philadelphia, Pennsylvania, 1981.
3. ASTM, Standard Method of Test for Rubber Property - Effect of Liquids, Designation D 471-79, Part 37, Philadelphia, Pennsylvania, 1981.
4. Hansen, Raymond, Laboratory Tests for Bituminous Seal-Coat Materials Specifications, MP-4-302, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1959.
5. Clark, J. I., and Watson, J. E., Maintenance of Porous Friction Surfaces, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, 1980.
6. MILSTD-620A, Unit Weight, Marshall Stability and Flow of Bituminous Mixtures, Method 100, Washington, DC, 1965.
7. MILSTD-620A, Gyratory Testing Machine Method of Design of Hot-Mix Bituminous Pavement, Method 102, Washington, DC, 1967.

APPENDIX A

COATINGS FOR FUEL-RESISTANT POROUS FRICTION SURFACE (PFS) PAVEMENTS: TENTATIVE MATERIAL SPECIFICATIONS

	<u>Page</u>
1. SCOPE	42
2. APPLICABLE DOCUMENTS	42
3. MATERIALS	42
3.1 Aggregate	42
3.2 Fuel-Resistant Coatings	44
4. SAMPLING AND TESTING	44
4.1 Sampling	44
4.2 Test Methods	44
5. ACCEPTANCE OF PRODUCT	48
5.1 Permeability	48
5.2 Fuel and Abrasion Resistance	48

1. SCOPE:

1.1 This specification covers the requirements and test procedures for the selection of coatings to produce a fuel-resistant porous friction surface (PFS). The fuel-resistant materials covered herein shall be used as coatings for existing PFS pavements. The material types can consist of epoxy resins, epoxy asphalt, coal tar epoxies, coal tar emulsions, or any product which demonstrates coating and fuel-resistant qualities.

2. APPLICABLE DOCUMENTS:

2.1 The current issues of the following standards form a part of this publication to the extent referenced:

2.1.1 U. S. Army Corps of Engineers, Handbook for Concrete and Cement:

CRD-C 119-53 Rev. June 63	Flat and Elongated Particles in Coarse Aggregate
------------------------------	--

2.1.2 American Society for Testing and Materials (ASTM) Publications:

C 29-78	Unit Weight and Voids in Aggregate
---------	------------------------------------

C 131-76	Resistance to Abrasion of Small-Size Coarse Aggregate
----------	---

D 471-77	Standard Test Method for Rubber Property--Effect of Liquids
----------	---

D 3387-78	Standard Test Method for Compaction and Shear Properties of Bituminous Mixtures by Means of the U. S. Army Corps of Engineers Gyrotory Testing Machine (GTM)
-----------	--

D 3910-80a	Standard Practices for Design, Testing, and Construction of Slurry Seal
------------	---

3. MATERIALS:

3.1 Aggregate: The aggregate used for constructing PFS coating laboratory specimens shall meet all the requirements of the following paragraphs.

3.1.1 General: Aggregates shall consist of crushed stone, crushed gravel, crushed slag, and screenings, as required. The portion of materials retained on the No. 4 sieve shall be known as coarse aggregate, the portion passing the No. 4 sieve and retained on the No. 200 sieve as fine aggregate, and the portion passing the No. 200 sieve as mineral filler.

3.1.2 Coarse aggregate shall consist of clean, sound, durable particles meeting the following requirements.

Percentages of loss shall not exceed 25 for airfields and 40 for roads after 500 revolutions, as determined in accordance with ASTM C 131.

The dry weight of crushed slag shall not be less than 75 pounds per cubic foot (pcf), as determined in accordance with ASTM C 29.

Crushed gravel retained on the No. 4 sieve and each coarser sieve shall contain at least 90 percent by weight of crushed pieces having at least one fractured face and 75 percent by weight of crushed pieces having two or more fractured faces. The area of each face shall be equal to at least 75 percent of the smallest midsectional area or piece. When two fractures are contiguous, the angle between planes of fractures shall be at least 30 degrees to count as fractured faces.

Particle shape of crushed aggregates shall be essentially cubical. Quantity of flat and elongated particles in any sieve size shall not exceed 8 percent by weight when determined in accordance with CRD C 119.

3.1.3 Fine aggregate shall consist of clean, sound, durable, angular particles produced by crushing stone, slag, or gravel that meet requirements for wear specified for coarse aggregate. Fine aggregate produced by crushing gravel shall have at least 90 percent by weight of crushed particles having two or more fractured faces in the portion passing the No. 4 sieve and being retained on the No. 30 sieve.

3.1.4 Aggregate gradation shall conform to gradation(s) specified in Table A-1. Table A-1 is based on aggregates of uniform specific gravity; the percentage passing various sieves shall be adjusted when aggregates of varying specific gravities are used.

TABLE A-1. AGGREGATE GRADATION FOR POROUS FRICTION SURFACE COATINGS, LABORATORY SPECIMENS.

Sieve Designation (Square Openings)	Percent Passing by Weight of Total Aggregates	
	Gradation A	Gradation B
	3/4 inch Maximum (Compacted Nominal Thickness, 1 inch)	1/2 inch Maximum (Compacted Nominal Thickness, 3/4 inch)
3/4 inch	100	100
1/2 inch	70-100	100
3/8 inch	45- 75	80-100
No. 4	25- 40	25- 40
No. 8	10- 20	10- 20
No. 30	3- 10	3- 10
No. 200	0- 5	0- 5

3.2 Fuel-Resistant Coatings: The product shall meet all the applicable requirements given below.

3.2.1 Single-Component Products: The materials used shall be homogeneous and show no separation or coagulation which cannot be overcome by moderate stirring.

3.2.2 Dual-Component Products: The materials used shall form a homogeneous mixture when combined in the manufacturer's required proportions.

3.2.3 Water and Additives: Water used for blending, rinsing, or wetting the pavement surface shall be potable. When additives are used for blending as antifreeze or antistripping agents, they shall not affect the product's effectiveness nor harm the underlying surface.

3.2.4 Material Curing Performance: The product shall be formulated so that the working life is sufficiently long to allow proper application of the material.

4. SAMPLING AND TESTING:

4.1 Sampling: The samples obtained for laboratory testing shall be representative of the material to be used for construction. These samples shall be stored in clean, airtight containers and maintained in a dry environment within a temperature range of 40°F to 120°F. The samples shall be furnished to the testing laboratory at least 30 days prior to planned use.

4.2 Test Methods:

4.2.1 Test Specimens: Test specimens shall consist of PCC concrete base cylinders with a 3/4-inch compacted PFS cap.

The base cylinder shall be prepared utilizing PCC concrete. Each cylinder shall be 5.95 ± 0.05 inches in diameter with a thickness of 2 ± 0.1 inches. A 6-inch concrete core provides an excellent source for the base cylinders.

PFS caps of 3/4 to 1 inch thickness shall be constructed on the concrete base cylinders, depending upon the PFS gradation used (CEGS-02562, AFM 88-6, Chapters 2 and 9). See Table A-1. Compaction of the PFS caps is accomplished with 10 revolutions of a gyratory compactor (ASTM D 3387) with a 1-degree angle of gyration and a 200-psi foot pressure setting of the machine.

The permit by weight of binder or asphalt content for the PFS specimen cap shall be determined from the formula $2k_c + 4.0$, where k_c is a factor obtained from the CKE Test Method (proposed ASTM Method). The type of asphalt used shall be an AC-20.

The controlling criteria for the amount of coating material applied are the maintenance of minimum permeability of 1000 ml/min and adequate fuel resistance.

After the PFS cap to be coated is prepared, the material shall be applied with a brush or sprayed when applicable. Care must be exercised to assure uniform and complete coverage. The test method requires coating the top of the PFS and completely covering the sides of the specimens. The final weight of the sealed specimens shall be recorded after the coating dries.

The temperature of all test specimens at the time of testing and during cure periods shall be maintained within a temperature range of 70°F + 10°. The time required for a complete cure will depend on the type of material used and should be based on the manufacturer's recommendations. An initial set shall be obtainable within 4 to 24 hours, and the material shall be rejected if it remains tacky after 24 hours. The specimens shall be maintained in a dry environment when not being tested.

4.2.2 Permeability Test:

The 6-inch diameter PFS samples are subjected to a falling-head permeability test. The average of three tests is taken as the permeability.

A permeability test device is used, containing the parts described below.

The standpipe is made of 1/4-inch thick clear lucite tubing, 13 inches high, with a 2 1/2-inch outside diameter. Included in a base plate of the same material, 2 inches thick, with an inside diameter of 2 1/2 inches and an outside diameter of 4 inches.

Permanent gradation marks are located on the standpipe of the assembled device from 1 to 10 inches, referenced from the bottom of the device.

The gasket is made of a soft rubber material,¹ approximately 1/4 inch thick. It is intended to prevent surface leakage between the bottom of the device and the PFS surface.

The cap is a 1/8-inch thick metal plate used as a loading surface for surcharge on the permeability device. It contains a raised rubber surface center 1/8 inch thick with a 1 15/16-inch diameter for secure centering on top of the device.

The valve is a 1/2-inch leaf valve in the water line to allow water to be pumped into the device and to be closed when running the permeability test.

The proving ring and meter are capable of accurately measuring the applied surcharge load of 100 pounds.

The swivel is any device which will allow for any axial deviations and prevent asymmetrical loading.

¹The gasket ring material used is manufactured as a typewriter pad, 0.24 inch thick, available from the 1980 General Services Administration's (GSA) Office Supply Catalog, Page 13, Column 1, part Number 7510-00-530-6412.

The water pump is capable of supplying water through a 1/2-inch hose into the standpipe faster than it will run out through the PFS (a minimum of 5000 ml/min is adequate in most circumstances). Other suitable means of providing water at the required ratio will be acceptable.

The stopwatch must have a minimum range of 5 minutes and an accuracy to the nearest second.

Any available lengths of hose which will fit between the leaf valve and the water pump and to a water source are acceptable.

Pans or other suitable containers to hold the water which passes through the specimens, and when necessary as a water reservoir, are required.

Place the PFS specimen within a pan or container, and place the permeability test device on the center of the specimen. Place a surcharge load of 100 pounds on the device.

Fill the permeability device with water until it begins discharging from the overflow opening; then seal off the flow of water with the valve.

Observe the time measured in seconds required for the water level in the device to drop from the 10-inch line to the 5-inch line. Perform a total of three tests on each specimen.

Record the average time for 5 inches of water loss, in seconds, for the three tests performed on each sample.

4.2.3 Fuel-Drip Test:

The PFS core sample is placed under a dripping flow of 1000 ml of fuel contained under 5 ± 0.5 pounds per square inch (psi) of pressure for 10 ± 0.5 minutes.

A container of any convenient size shall be used, provided it can hold a minimum of 1000 ml of Reference Fuel B. This container shall be capable of being pressurized at a constant 5 ± 0.5 psi. and possess valving capable of being calibrated to deliver 1000 ml in 10 ± 0.5 minutes. The discharge on this container shall be capable of dripping the fuel to evenly cover the entire core surface for the required time.

The balance shall be capable of weighing 5000 grams to within ± 1 gram.

The fuel used in the fuel-drip test shall be Reference Fuel B (70 percent isooctane plus 30 percent toluene, industrial grade) (ASTM D 471).

A wire mesh or screen shall be used, on which the sample is placed, to allow drainage of fuel away from the sample.

Utilizing the container described above, apply to a sample within 10 ± 0.5 minutes 1000 ml of fuel contained under 5 ± 0.5 psi of pressure. The

sample shall be rotated 90 degrees every 2.5 minutes to assure equal fuel coverage to the sample.

Afterward, test the sample by abrasion within 30 ± 1 minutes of completion of the fuel-drip test.

Record any visible damage or loss of PFS aggregate from the specimen.²

4.2.4 Abrasion Test: The specimens shall be tested by abrasion using an adaptation of the "Wet Track Abrasion Test," ASTM D 3910. The following test method contains sections of ASTM D 3910 either copied verbatim, adapted to this test method, or completely eliminated.

The specimen is abraded at the temperature requirements given in Section 4.2.1. After abrasion, the specimen is dried to a constant weight as specified, and the weight is recorded.

A balance capable of weighing 5000 grams to within ± 1 gram shall be used.

The Planetary Type Mechanical Stirrer³ (such as the Hobart C-100 made by Hobart Mfg. Co., Troy, Ohio) shall be equipped with a (5-pound) weighted rubber hose holding device (abrasion head) with approximately 1/2 inch free up-and-down movement in the shaft sleeve.

A heavy (1/8-inch) flat-bottom metal pan shall be selected that is approximately 13 inches in diameter with 2-inch vertical side walls (20-gage or heavier) having four equispaced screw clamps capable of securing the 1 1/4-inch diameter specimen holders to the bottom of the pan.

A specimen holder constructed with polymethylmethacrylate (PMMA) shall hold the specimens securely in the metal pan. The device is 1/4 inch in thickness with an outside diameter of 11 inches and an inside diameter of 6.1 ± 0.1 inches to be centered under the rotating head of the mechanical stirrer when the pan is attached to it. This device shall be capable of holding the samples immobile during the abrasion test.

Reinforced rubber hose⁴ (two-braid, 300 psi, green oil-resistant cover), with a 3/4-inch inside diameter and 1-7/32 inch outside diameter, shall be cut into 1-1/2-inch lengths.

²When a specimen loses pieces of aggregate during the fuel test, the abrasion test may be waived and the product failed when approximately 10 percent or more of the PFS aggregate is lost.

³The Hobart C-100 stirrer, available from Hobart Manufacturing Co., World Headquarters, Troy, Ohio 45374, has been found suitable.

⁴The Uniroyal P-290 general purpose air hose, available from Uniroyal, Inc., PO Box 1126, Wall Street Station, New York, NY 10005, has been found suitable.

Wooden prop block or equivalent is required for supporting the platform assembly into position during testing.

Place the sample in the holder and secure it in the large pan by the provided fasteners. Add water at room temperature to cover the sample by at least 1/4 inch.

Secure the pan containing the specimen on the platform of the device. Lock the rubber hose abrasion head on the shaft of the Hobart machine. Elevate the platform until the rubber hose fully contacts the sample with the total weight of the head on the surface of the specimen. Use the prop block to support the platform assembly during testing.

Switch to the low speed of the machine (approximately 144 shaft rpm at 61 turns of the planetary). Operate the machine for 5 minutes \pm 2 seconds running time.⁵

Remove the specimen and rinse it thoroughly with water to remove all loose debris. Then place the specimen in a clean, dry area and allow it to dry to a constant weight.

Record the final weight of the specimen after abrasion, noting any loss of aggregate particles from the specimen.

5. ACCEPTANCE OF PRODUCT:

5.1 Permeability: The product shall be rejected as a coating if it lowers the permeability of the average of the three PFS specimens below 1000 ml/min. Rejected products shall be retested one additional time.

5.2 Fuel and Abrasion Resistance:

5.2.1 The product shall be rejected if, at any time during the fuel/abrasion tests, there is a weight loss (loss of aggregate/coating material) from any of the specimens which exceeds the weight of the coating originally applied. If this weight loss is exceeded on one of the three PFS specimens, the product shall be retested.

⁵Install a fresh section of hose after completion of each test to prevent any material buildup on the base. It is allowable to rotate the hose one-half turn after one test so that two tests can be conducted with each piece of hose.

TECHNICAL NOTES

- A. These requirements and test procedures serve as a guide for the selection of suitable coatings for fuel-resistant porous friction surfaces rather than for quality control during construction of pavements. However, the designer is encouraged to use the applicable requirements and test procedures in the quality control section of his contract specifications.
- B. This specification will retain the "tentative" designation until sufficient field experience has proven its total reliability.

APPENDIX B

BINDERS FOR FUEL-RESISTANT POROUS FRICTION SURFACE (PFS) PAVEMENTS: TENTATIVE MATERIAL SPECIFICATIONS

	<u>Page</u>
1. SCOPE	51
2. APPLICABLE DOCUMENTS	51
3. MATERIALS	51
3.1 Aggregate	51
3.2 Fuel-Resistant Binders	53
4. SAMPLING AND TESTING	53
4.1 Sampling	53
4.2 Test Methods	53
5. ACCEPTANCE OF PRODUCT	57
5.1 Permeability	57
5.2 Fuel and Abrasion Resistance	57

1. SCOPE:

1.1 This specification covers the requirements and test procedures for the selection of binders to produce a fuel-resistant porous friction surface (PFS). The fuel-resistant materials covered herein shall be used as binders for construction of new PFS pavements. The material types can consist of epoxy resins, epoxy asphalt, coal tar epoxies, coal tar emulsions, or any product which demonstrates binder fuel-resistant qualities.

2. APPLICABLE DOCUMENTS:

2.1 The current issues of the following standards form a part of this publication to the extent referenced:

2.1.1 U. S. Army Corps of Engineers, Handbook for Concrete and Cement:

CRD-C 119-53 Rev. June 63	Flat and Elongated Particles in Coarse Aggregate
------------------------------	--

2.1.2 American Society for Testing and Materials (ASTM) Publications:

C 29-76	Unit Weight and Voids in Aggregate
C 136-76	Sieve or Screen Analysis of Fine and Coarse Aggregates
D 471-77	Standard Test Method for Rubber Property--Effect of Liquids
D 3387-78	Standard Test Method for Compaction and Shear Properties of Bituminous Mixtures by Means of the U. S. Army Corps of Engineers Gyratory Testing Machine (GTM)
D 3910-80a	Standard Practices for Design, Testing, and Construction of Slurry Seal

3. MATERIALS:

3.1 Aggregate: The aggregate used for constructing PFS binder laboratory specimens shall meet all the requirements of the following paragraphs.

3.1.1 General: Aggregates shall consist of crushed stone, crushed gravel, crushed slag, and screenings, as required. The portion of materials retained on the No. 4 sieve shall be known as coarse aggregate, the portion passing the No. 4 sieve and retained on the No. 200 sieve as fine aggregate, and the portion passing the No. 200 sieve as mineral filler.

3.1.2 Coarse aggregate shall consist of clean, sound, durable particles meeting the following requirements.

Percentages of loss shall not exceed 25 for airfields and 40 for roads after 500 revolutions, as determined in accordance with ASTM C 131.

The dry weight of crushed slag shall not be less than 75 pcf, as determined in accordance with ASTM C 29.

Crushed gravel retained on the No. 4 sieve and each coarser sieve shall contain at least 90 percent by weight of crushed pieces having at least one fractured face and 75 percent by weight of crushed pieces having two or more fractured faces, with the area of each face equal to at least 75 percent of the smallest midsectional area of piece. When two fractures are contiguous, the angle between planes of fractures shall be at least 30 degrees to count as fractured faces.

Particle shape of crushed aggregates shall be essentially cubical. Quantity of flat and elongated particles in any sieve size shall not exceed 8 percent by weight when determined in accordance with CRD C 119.

3.1.3 Fine aggregate shall consist of clean, sound, durable, angular particles produced by crushing stone, slag, or gravel that meets requirements for wear specified for coarse aggregate. Fine aggregate produced by crushing gravel shall have at least 90 percent by weight of crushed particles having two or more fractured faces in the portion passing the No. 4 sieve and retained on the No. 30 sieve.

3.1.4 Aggregate gradation shall conform to gradation(s) specified in Table B-1. Table B-1 is based on aggregates of uniform specific gravity; the percentage passing various sieves shall be adjusted when aggregates of varying specific gravities are used.

TABLE B-1. AGGREGATE GRADATION FOR POROUS FRICTION SURFACE BINDERS, LABORATORY SPECIMENS.

Sieve Designation (Square Openings)	Percent Passing by Weight of Total Aggregates	
	Gradation A	Gradation B
	3/4 inch Maximum (Compacted Nominal Thickness, 1 inch)	1/2 inch Maximum (Compacted Nominal Thickness, 3/4 inch)
3/4 inch	100	100
1/2 inch	70-100	100
3/8 inch	45- 75	80-100
No. 4	25- 40	25- 40
No. 8	10- 20	10- 20
No. 30	3- 10	3- 10
No. 200	0- 5	0- 5

3.2 Fuel-Resistant Binders: The product shall meet all the applicable requirements given below.

3.2.1 Single-Component Products: The materials used shall be homogeneous and show no separation or coagulation which cannot be overcome by moderate stirring.

3.2.2 Dual-Component Products: The materials used shall form a homogeneous mixture when combined in the manufacturer's required proportions.

3.2.3 Water and Additives: Water used for blending, rinsing, or wetting the pavement surface shall be potable. When additives are used for blending as antifreeze or antistripping agents, they shall not affect the product's effectiveness nor harm the underlying surface.

3.2.4 Material Curing Performance: The product shall be formulated so that the working life is sufficiently long to allow the use of specified equipment to mix and lay down the new PFS so that performance requirements are satisfied.

4. SAMPLING AND TESTING:

4.1 Sampling: The samples obtained for laboratory testing shall be representative of the material to be used for construction. These samples shall be stored in clean, airtight containers and maintained in a dry environment within a temperature range of 40°F to 120°F. The samples will be furnished to the testing laboratory at least 30 days prior to planned use.

4.2 Test Methods:

4.2.1 Test Specimens: Test specimens shall consist of PCC concrete base cylinders with a 3/4-inch compacted PFS cap.

The base cylinder shall be prepared utilizing PCC concrete. Each cylinder shall be 5.95 ± 0.05 inches in diameter with a thickness of 2 ± 0.1 inches. A 6-inch concrete core provides an excellent source for the base cylinders.

PFS caps of 3/4 to 1 inch thickness shall be constructed on the concrete base cylinders, depending upon the PFS gradation used (see Table B-1). Compaction of the PFS caps is accomplished with 10 revolutions of a gyratory compactor (ASTM D 3387) with a 1-degree angle of gyration and a 200-psi foot pressure setting of the machine.

Two factors controlling the amount of binder required in the PFS mix are the addition of binder until excessive bleeding occurs or until the permeability of the specimen falls below 1000 ml/min. The formula $2k_c + 4.0$ will give an initial binder content which can then be adjusted up or down as necessary. k_c is a factor obtained from CKE test method (ASTM D 3910) (ASTM 1982). This formula is derived, using a binder specific gravity of approximately 1.0; any variations from this must be taken into account to achieve a correct content.

The temperature of all test specimens at the time of testing and during cure periods shall be maintained within a temperature range of

70°F ± 10°. The time required for a complete cure will depend on the type of material used and should be based on the manufacturer's recommendations. The specimens shall be maintained in a dry environment when not being tested.

4.2.2.1 Summary of Method:

The 6-inch-diameter PFS samples are subjected to a falling-head permeability test. The average of three tests is taken as the permeability.

The standpipe is made of 1/4-inch thick clear lucite tubing, 13 inches high, with a 2 1/2-inch outside diameter. Included is a base plate of the same material, 2 inches thick, with an inside diameter of 2 1/2 inches and an outside diameter of 4 inches.

Permanent gradation marks are located on the standpipe of the assembled device from 1 to 10 inches, referenced from the bottom of the device.

The gasket is made of a soft rubber material,¹ approximately 1/4-inch thick. It is intended to prevent surface leakage between the bottom of the device and the PFS surface.

A 1/8-inch thick metal plate is used as a loading surface for surcharge on the permeability device. It contains a raised rubber surface center 1/8-inch thick with a 1 15/16-inch diameter for secure centering on top of the device.

A 1/2-inch leaf valve in the water line allows water be pumped into the device and is closed when running the permeability test.

The proving ring and meter shall be capable of accurately measuring the applied surcharge load of 100 pounds.

A swivel shall be used to prevent any axial deviations and prevent asymmetrical loading.

The water pump shall be capable of supplying water through a 1/2-inch hose into the standpipe faster than it will run out through the PFS (a minimum of 5000 ml/min is adequate in most circumstances). Other suitable means of providing water at the required ratio will be acceptable.

The stopwatch shall have a minimum range of 5 minutes and an accuracy to the nearest second.

The hose shall be in any available lengths which will fit between the leaf valve and the water pump and to a water source.

Pans or other suitable containers shall be used to hold the water which passes through the specimens and, when necessary, as a water reservoir.

¹The gasket ring material used is manufactured as a typewriter pad, 0.24 inches thick, available from the 1980 General Services Administration's (GSA) Office Supply Catalog, Page 13, Column 1, part Number 7510-00-530-6412.

Place the PFS specimen within a pan or container, and place the permeability test device on the center of the specimen. Place a surcharge load of 100 pounds on the device.

Fill the permeability device with water until it begins discharging from the overflow opening. Then seal off the flow of water with the valve.

Observe the time measured in seconds required for the water level in the device to drop from the 10-inch line to the 5-inch line. Perform a total of three tests on each specimen.

Record the average time for 5 inches of water loss, in seconds, for the three tests performed on each sample.

4.2.3 Fuel-Drip Test:

The PFS core sample is placed under a dripping flow of 1000 ml of fuel contained under 5 ± 0.5 psi of pressure for 10 ± 0.5 minutes.

A container of any convenient size shall be provided to hold a minimum of 1000 ml of Reference Fuel B. This container shall be capable of being pressurized at a constant 5 ± 0.5 psi and possess valving capable of being calibrated to deliver 1000 ml in 10 ± 0.5 minutes. The discharge on this container shall be capable of dripping the fuel to evenly cover the entire core surface for the required time.

A balance shall be capable of weighing 5000 grams to within ± 1 gram.

The fuel used in the fuel-drip test shall be Reference Fuel B (70 percent isooctane plus 30 percent toluene, industrial grade (ASTM D 471)).

A wire mesh or screen shall be used, on which the sample is placed, to allow drainage of fuel away from the sample.

In the container described above, 1000 ml of fuel contained under 5 ± 0.5 psi of pressure shall be applied to a sample within 10 ± 0.5 minutes. The sample shall be rotated 90 degrees every 2.5 minutes to assure equal fuel coverage to the sample.

After the fuel test, the sample shall be tested by abrasion within 30 ± 1 minutes of completion of the fuel-drip test.

Record any visible damage or loss of PFS aggregate from the specimen.²

4.2.4 Abrasion Test: The specimens shall be tested by abrasion by an adaptation of the "Wet Track Abrasion Test," ASTM D 3910. The following test

²When a specimen loses pieces of aggregate during the fuel test, the abrasion test may be waived and the product failed when approximately 10 percent or more of the PFS aggregate is lost.

method contains sections of ASTM D 3910, either copied verbatim, adapted to this test method, or completely eliminated.

The specimen is abraded at the temperature requirements given in Section 4.2.1. After abrasion, the specimen is dried to a constant weight as specified, and the weight is recorded.

The balance shall be capable of weighing 5000 grams to within + 1 gram.

The planetary Type Mechanical Stirrer³ (such as the Hobart C-100 made by Hobart Mfg. Co., Troy, Ohio) shall be equipped with a (5-pound) weighted rubber hose holding device (abrasion head) with approximately 1/2-inch free up-and-down movement in the shaft sleeve.

A heavy (1/8-inch) flat-bottom metal pan shall be used. This pan shall be approximately 13 inches in diameter with 2-inch vertical side walls (20-gage or heavier) having four equispaced screw clamps capable of securing 11 1/4-inch diameter specimen holders to the bottom of the pan.

The specimen holder which is constructed with polymethylmethacrylate (PMMA) holds the specimens securely in the metal pan. The device is 1/4 inch in thickness with an outside diameter of 11 inches and an inside diameter of 6.1 ± 0.1 inches to be centered under the rotating head of the mechanical stirrer when the pan is attached to it. This device shall be capable of holding the samples immobile during the abrasion test.

The reinforced rubber hose⁴ shall have a two-braid, 300 psi, green oil-resistant cover with a 3/4-inch inside diameter and a 1 7/32-inch outside diameter. The hose shall be cut into 1 1/2-inch lengths.

A wooden prop block or equivalent shall be provided for supporting the platform assembly into position during testing.

Place the sample in the holder and secure it in the large pan by the provided fasteners. Add water at room temperature to cover the sample by at least 1/4 inch.

Secure the pan containing the specimen on the platform of the device. Lock the rubber hose abrasion head on the shaft of the Hobart machine. Elevate the platform until the rubber hose fully contacts the sample with the total weight of the head on the surface of the specimen. Use the prop block to support the platform assembly during testing.

³The Hobart C-100 stirrer, available from Hobart Manufacturing Co., World Headquarters, Troy, Ohio 45374, has been found suitable.

⁴The Uniroyal P-290 general purpose air hose, available from Uniroyal, Inc., PO Box 1126, Wall Street Station, New York, NY 10005, has been found suitable.

Switch to the low speed of the machine (approximately 144 shaft rpm at 61 turns of the planetary). Operate the machine for 5 minutes + 2 seconds running time.⁵

Remove the specimen and rinse it thoroughly with water to remove all loose debris. Then place the specimen in a clean, dry area and allow it to dry to a constant weight.

Record the final weight of the specimen after abrasion. Note any loss of aggregate particles from the specimen.

5. ACCEPTANCE OF PRODUCT:

5.1 Permeability: The product shall be rejected if the permeability of the average of the three PFS specimens is below 1000 ml/min. Rejected products shall be retested.

5.2 Fuel and Abrasion Resistance:

5.2.1 Binders: The product shall be rejected if, at any time during the fuel and/or abrasion tests, there is a weight loss (loss of aggregate or binder material) from any of the specimens which exceeds the weight of the binder in the test specimen.

When this weight loss is exceeded by one of the three specimens, the product shall be retested.

⁵Install a fresh section of hose after completion of each test to prevent any material buildup on the base. It is allowable to rotate the hose one-half turn after one test so that two tests can be conducted with each piece of hose.

TECHNICAL NOTES

- A. These requirements and test procedures serve as a guide for selection of suitable binders for fuel-resistant porous friction surfaces rather than for quality control during the construction of pavements. However, the designer is encouraged to use the applicable requirements and test procedures in the quality control section of his contract specifications.
- B. This specification will retain the "tentative" designation until sufficient field experience has proven its total reliability.

APPENDIX C

CONVERSION FACTORS, U. S. CUSTOMARY (NON-SI) TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary (NON-SI) units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
Fahrenheit degrees	5/9	Celsius degrees ^a
feet	0.3048	meters
gallons (U. S. liquid)	3.7852	liters
inches	2.54	centimeters
ounces	28.350	grams
pounds (force) per square inch	6894.757	pascals
pounds (mass)	0.454	kilograms
pounds per cubic foot	16.01	kilograms per cubic meter

^a To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$.